Lake Trout in Ontario
Management Strategies

Lake Trout Synthesis
Management Strategies Working Group
1991

Ontario
Ministry of
Natural
Resources

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FOREWORD

Our understanding of lake trout, although drawn from decades of study, remains incomplete. The Lake Trout Synthesis was designed to assemble the scientific information about lake trout and to distil it into a form that will encourage wise and sustainable management of the species. This report provides the opportunity to address our concerns about lake trout and to propose actions for perpetuating the species in Ontario.

Lake trout offer unique challenges and opportunities for managers. While the Ontario Ministry of Natural Resources[1] is vested with the principal custodial responsibilities for lake trout management, all Ontarians should share a strong sense of stewardship for this species. Our report sets the stage for engendering such an attitude.

The lake trout is unique and a paradox. Its inherent needs dictate that it must live in cold, unproductive lakes. It is highly vulnerable to stresses of human origin, yet manages to persist in the face of the many threats to its existence. Lake trout are a readily recognizable indicator of the health of oligotrophic aquatic ecosystems.

Although the focus of this report is the lake trout, the report has broad application for the management of aquatic ecosystems and other types of fish communities and fish species in general.

We dedicate the "Lake Trout Synthesis" to the memory of Nigel V. (Nick) Martin, (1920-1986). Throughout his career with OMNR, Nick steadfastly whittled away at the many questions that lake trout pose for enquiring minds. We have built upon his work and insights and hopefully progressed, at least a little farther.

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[1]Hereafter, also referred to as the "Ministry of Natural Resources", the "Ministry", and "OMNR".

INTRODUCTION

The lake trout (*Salvelinus namaycush*) has a long and venerable history in Ontario. The French explorer, Samuel de Champlain, was the first European known to comment about the lake trout. He referred to the enormous trout in Georgian Bay ("des truittes qui sont monstreusements grandes") up to four and a half feet long with the smallest two and a half feet in length (Champlain 1619). In what later became known as Ontario, the lake trout was an important part of the diet of the original peoples and later of the fur traders, missionaries, explorers, and settlers. In the Great Lakes, large commercial fisheries for lake trout flourished until the late 1940s and early 1950s. Thriving, but largely hatchery-dependent sport fisheries for lake trout have developed in these lakes, particularly in the last twenty years. Recreational fisheries for lake trout exist in many inland lakes in the province.

There are indications that the lake trout resource in many areas of the province is in jeopardy. Some lake trout populations have become extinct and others are threatened. There has been a general decline in the quality of the sport fishery for lake trout and in its habitat in many lakes. Rehabilitation, where attempted, has been an excruciatingly slow process. Indeed, of all the fish species native to the province, the lake trout probably represents the largest challenge to managers because of its sensitivity to exploitation and to alterations to its environment.

Concern about depletion of lake trout resources and their management is explained by:

- the stringent life history and habitat requirements of the lake trout;
- the inefficient and ineffective manner in which the fisheries have been managed;
- overexploitation of stocks and cumbersome control strategies;
- inadequate protection, maintenance, and rehabilitation of aquatic habitat;
- the impact of fish stocking and species introductions on native lake trout stocks; and
- costly monitoring programs and inadequate methodologies for comparing results among lakes.

Appreciating the need for concerted remedial action and a long-term management strategy for lake trout, the provincial Fisheries Policy Committee approved, in February, 1987, the formation of six working groups (Population Dynamics, Community Biology, Sampling Issues and Methodology, Response to Stress, Physiology and Ecology, and Management Strategies) to summarize existing information about lake trout in the province and to determine management

options and strategies to perpetuate healthy lake trout stocks. The process of data compilation, analysis, report preparation, and model development came to be known as the Lake Trout Synthesis.

The **GOAL** of the Lake Trout Synthesis has been to:

> **SUMMARIZE EXISTING MATERIAL AND GENERATE NEW KNOWLEDGE ABOUT LAKE TROUT COMMUNITIES AND THEIR RESPONSES TO MANAGEMENT ACTIONS AND STRESSES, AND TO TRANSLATE THIS INFORMATION INTO RECOMMENDATIONS FOR FISHERIES MANAGERS**

Five working groups commenced their tasks in April, 1987. The Management Strategies working group started in April, 1988. Terms of reference for this working group are presented in Appendix A. Membership in the working groups generally consisted of a mix of resource managers, research scientists, and fisheries assessment unit (FAU) biologists.

Although the reports of the other working groups were used extensively in the preparation of our report, other sources have also been used. These include concepts and insights outside the purview of the Lake Trout Synthesis, approaches to lake trout management used in other jurisdictions, and the individual and collective experiences of the authors.

The focus of the synthesis has been on the science underlying inland natural lake trout populations. Few Great Lakes stocks are self-sustaining and the synthesis has drawn heavily on information about inland lake trout lakes and their fisheries. As well, Great Lakes lake trout stocks have a unique stress - the sea lamprey (*Petromyzon marinus*) - which must be excluded from any consideration of inland lake trout stock dynamics. There are few commercial fisheries for lake trout in Ontario. Lake trout may be taken for commercial purposes in only 19 lakes and 98% of the total provincial commercial quota for lake trout harvest occurs on three lakes - Superior, Huron and Nipigon (Olver 1988). Consequently, the synthesis has relied mainly on data from recreational fisheries. While the details of managing sport and commercial fisheries may vary, the principles on which their management is based are the same.

Factors external to the lake trout itself have an important influence on charting directions for lake trout management. A heightened interest in environmental matters by the general public is evident as we move into the 1990s. All the people of Ontario - not just special interest groups - are recognized as stakeholders. New societal values are emerging about the nurturing and care of natural resources. At a global level, there are pervasive concerns about the future of the planet. Issues include global warming, habitat and species loss, acid and toxic rain, and contaminants - all of which affect the lake trout.

At the provincial level, the Strategic Plan for Ontario Fisheries (OMNR 1990), commonly referred to as SPOF II, identifies the problems threatening Ontario's fisheries resource - decline in ecosystem health (and the loss of fish habitat), loss of fish, and shareholder conflicts. It is also evident that healthy ecosystems are a prerequisite for healthy fish stocks and for sustainable development. The management of lake trout should, therefore, be based on the principle that it is a key indicator of the health of oligotrophic ecosystems. Thus, within the framework of SPOF II, there is the immediate challenge and hence, opportunity to implement measures that will perpetuate the lake trout in Ontario.

Lake trout are an important component of Ontario's fisheries resource. They are sensitive to many stresses and thus present an excellent example of the widespread public concern about the degradation of natural resources. The inherent aesthetic values and environmental quality of the lakes it inhabits and society's desire to provide a healthy environment for succeeding generations make it opportune to create new management directions for lake trout.

Lake trout management in Ontario must embody the new strategic directions being undertaken by the Ministry of Natural Resources. Specifically, the Lake Trout Synthesis will generate better information for managing lake trout. The goal statement and the recommendations in this report define new strategic directions for lake trout management at the species, community, and ecosystem levels. They emphasize maintenance and rehabilitation of both lake trout stocks and their habitats. These strategies are consistent with and build upon recent and developing corporate directions (Appendix B).

A PERSPECTIVE ON THE LAKE TROUT

The lake trout is indigenous only to North America. In Ontario, about 2200 lakes contain lake trout. Although this is less than one percent of the lakes in the province, they represent a substantial part, perhaps 20-25%, of those occurring in the world. The province has, with the possible exception of Quebec and the Northwest Territories, more lake trout lakes and, including Ontario's portion of the Great Lakes, a larger area of lake trout waters than any other jurisdiction. Hence, Martin and Olver (1976) concluded that the province of Ontario has the greatest responsibility of any government for the management of this species.

The lake trout is an important fishery resource in Ontario. The social and economic benefits of lake trout to the province and its citizens are considerable. Based on a 1985 survey of sport fishing in Ontario (Bedi et al. 1990) it is estimated that about 290,000 or 18.5% of all resident anglers, and 89,000 or 15% of non-resident anglers listed lake trout among their most preferred species. It has been estimated that 21% of all sport fishing on both sides of the Great Lakes is directed at lake trout and that this activity provides more than three million angler-days annually (Boulanger and Charbonneau 1989). The lake trout sport fishery in Ontario's inland lakes provides approximately an equivalent number of angler-days (N. Bedi, OMNR 99 Wellesley St. W., Toronto, Ont. M7A 1W3, pers. comm.). Based on this estimate and applying a "willingness to pay" value of $35.00 per angler-day (Boulanger and Charbonneau 1989), the value of the lake trout sport fishery on the inland lakes alone is worth in excess of 100 million dollars annually.

In Ontario, the lake trout is confined almost exclusively to the recently glaciated lakes of the Canadian Shield and the Great Lakes (Martin and Olver 1976; Fig. 1). These areas are:

- the northwest part of the province south of the Hudson Bay lowlands from the Manitoba border to Lake Superior;
- the area east of Lake Superior to the Quebec border; and
- south-central Ontario between Georgian Bay and the middle reaches of the Ottawa River.

Lake trout lakes in Ontario are generally "larger, of higher altitude, deeper, clearer, colder, better oxygenated, more acidic, softer and lower in total alkalinity, buffering capacity, total dissolved solids and morphoedaphic index [productivity] values" than non-lake trout lakes

(Martin and Olver 1976).

Introductions of lake trout into lakes previously devoid of the species account for about 10% of the lake trout lakes in the province (Lewis et al. 1990). As a result of extensive stocking efforts, most lakes suitable for lake trout now contain the species. Consequently, it is not likely that the total number of lake trout lakes in Ontario can be increased substantially through stocking.

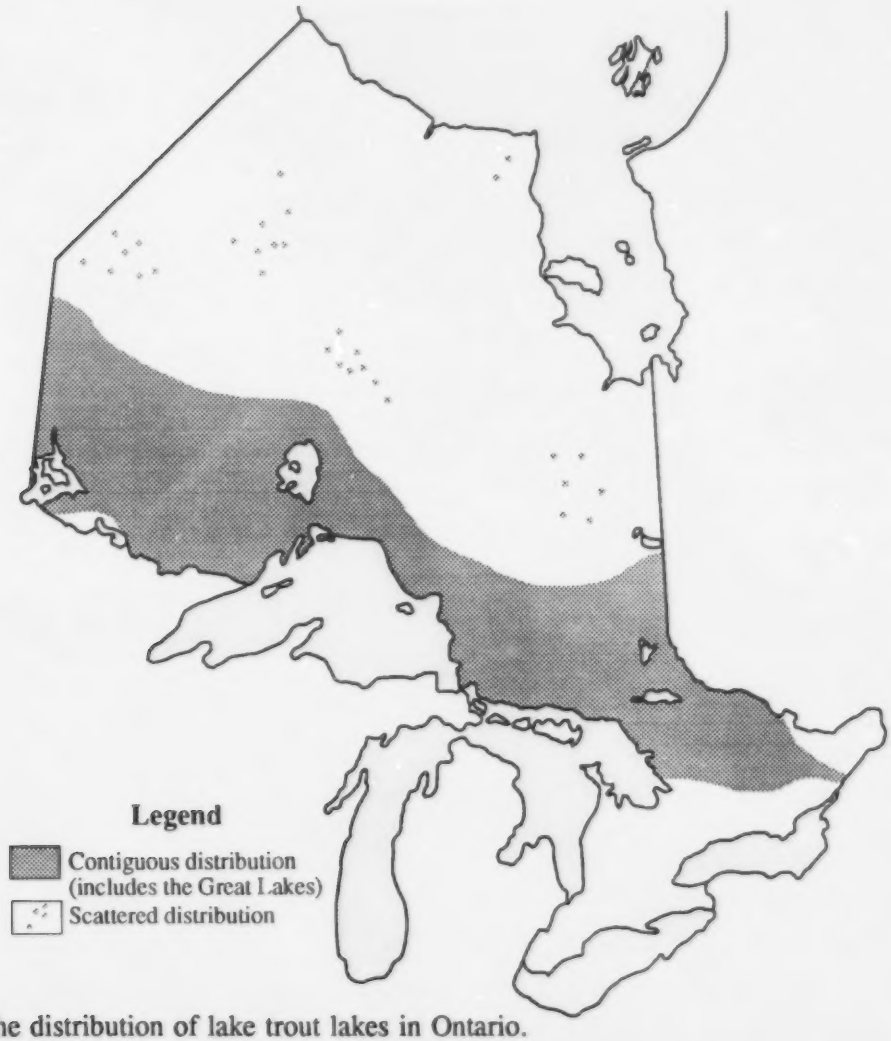

Fig. 1. The distribution of lake trout lakes in Ontario.

Ryder (1972) noted that the lake trout is perhaps the most representative species of oligotrophic lakes. Ryder and Johnson (1972) characterized oligotrophic lakes as "swimming pools carved out of granite, with low nutrient tributaries and a cold annual thermal regime" which are "capable of having their environment and their communities severely altered - only too easily". Behnke (1972) described the lake trout as a species with a "highly specialized mode of life with narrow environmental tolerances limiting the opportunities for adaptation to new types of habitat and diverse niches". Thus, the lake trout is a sensitive species which acts as an environmental indicator of the health of the fragile aquatic ecosystems that it inhabits.

In Ontario, the lake trout is the only major, indigenous sport fish species adapted to the deep, cold waters of oligotrophic lakes. If lake trout stocks collapse, they are not replaced by any other species which fulfils a similar role in the fish community, or which afford a comparable angling experience. The lake trout is a keystone predator in that it integrates community structure by affecting or controlling community diversity and stability (Evans et al. 1987). The lake trout also acts as an integrator species by recycling energy and nutrients between the shallow, inshore littoral zone and the deep offshore waters (Christie 1972).

The inherent biological attributes of lake trout (slow growth, late maturity, low reproductive potential, long life expectancy and slow turnover or replacement rate) are a function of its adaptation to cold, infertile lakes. Lake trout require spawning sites with clean cobble, free from vegetation and sediment, and cold, well-oxygenated water throughout the year. During the period of thermal stratification they are confined mainly to the deepest waters of lakes. As a consequence of these stringent life history and habitat requirements, lake trout only occur in relatively few, unproductive lakes where they form sparse populations which produce low, annual sustainable yields (Fig. 2).

Many lake trout stocks in Ontario are in trouble. Overexploitation is considered by managers to be the most important stressor affecting lake trout (Lewis et al. 1990). Naturally reproducing stocks have become extinct in about 5% of the lake trout waters in the province (Lewis et al. 1990) - mainly due to some form of habitat degradation. In an increasing number of lakes, only

remnant native lake trout stocks remain. Stocking non-native stocks in the presence of native stocks is a stressor which occurs in 16% of the lakes in the province which contain native lake trout (categories N1, N3 in Lewis et al. 1990). Some 12.5% of Ontario lake trout lakes are extremely sensitive to acidification (Beggs et al. 1985). Thus, many lake trout lakes in Ontario have been subject to some type of anthropogenic stressor in the past 30-50 years.

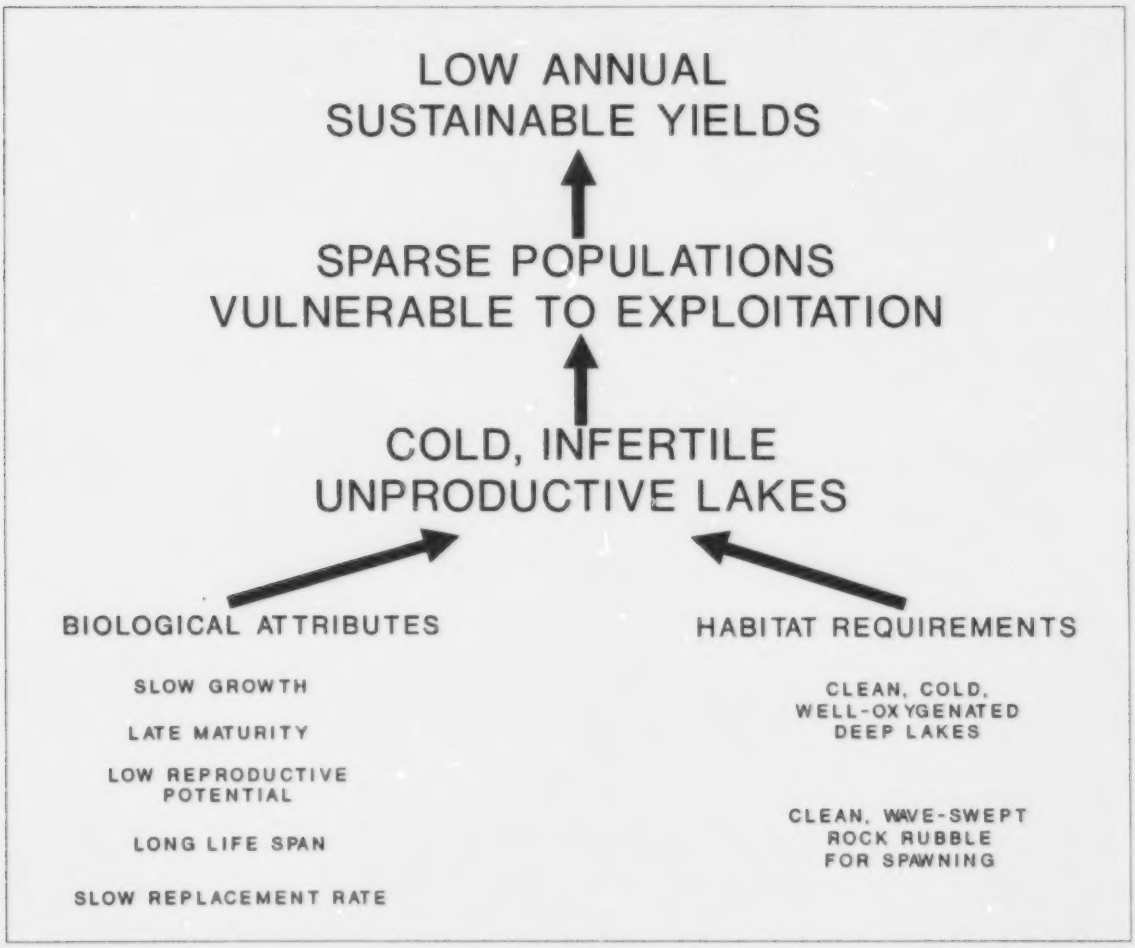

Fig. 2. Productivity of lake trout and lake trout lakes relative to their biological attributes and habitat requirements.

ADMINISTERING THE FISHERIES

Ontario's fisheries resources are administered through diverse legislative and institutional mechanisms. This creates a complex administrative environment in which to manage the fisheries. Scientific knowledge about fish stocks and their habitats alone is not sufficient to ensure the perpetuation of healthy aquatic ecosystems. Managers must also understand the "rules and regulations" which govern the administration of the fisheries.

The management of Ontario's fisheries is a shared responsibility of the provincial and federal governments. Pursuant to the British North America Act, the federal government has the constitutional authority to protect, regulate, and preserve Canada's fish resources (Thompson 1974), while the Ontario government is responsible for the administration and management of fisheries within the province. This responsibility is executed through the Federal Fisheries Act and the Ontario Fisheries Regulations. The provincial Game and Fish Act governs the licensing of various fisheries, and the transportation and sale of fish.

Although the Ministry of Natural Resources bears the primary responsibility for fisheries management in Ontario, 18 federal and 12 provincial agencies administer acts and regulations that affect the fisheries resources (OMNR and Environ. Canada 1976). These overlapping responsibilities can cause delays and confusion in administering the fisheries.

The provincial acts which control activities in and around water include the Public Lands Act, the Lakes and Rivers Improvement Act, and the Planning Act. The Public Lands Act controls the occupation of Crown lands and the beds of most water bodies, and activities such as dredging and filling on shorelands. The Lakes and Rivers Improvement Act protects riparian interests, largely associated with works that hold back or divert water. The Planning Act provides the legislative authority for input to and review of municipal Official Plans and plans for private developments. It identifies "matters of provincial interest", allows for site plan control, subdivisions, consents, zoning bylaws, and specifies how Official Plans and their amendments interact, and provides for arbitration of disputes by the Ontario Municipal Board (OMB). An Official Plan is of special significance in that it outlines policy and direction for

development within a municipality, with regard to social, economic and environmental interests. These provincial statutes contain penalty provisions and provide for approval and compliance mechanisms to control development. However, the workload associated with the review of numerous applications (up to 3,000 annually in some districts) is straining staff resources.

Some municipalities are reluctant to identify fish habitat specifically in their official plans, preferring to designate these areas within a general "environmental protection" zone. Within OMNR, lack of adequate habitat inventory often necessitates a time-consuming and cumbersome case-by-case approach. As a result, review of Official Plans to meet statutory deadlines imposed by the Planning Act is sometimes cursory.

We need an ongoing, proactive approach to land use decision-making. Specific recognition of lake trout lakes in Official Plans should reduce the need for extensive review of lower level planning documents. Also, it would put both developers and municipalities on early notice that OMNR has major concerns about development and raise the profile of lake trout lakes as sensitive environments that require protection. We **recommend** that:

MANAGERS TAKE ADVANTAGE OF PLANNING PROCESSES THAT PROVIDE OPPORTUNITIES FOR LAND USE DESIGNATIONS WHICH PROTECT LAKE TROUT LAKES

THE PROVINCE'S SPECIAL CONCERNS ABOUT ONTARIO LAKE TROUT LAKES BE ADDRESSED BY MUNICIPALITIES IN OFFICIAL PLANS

Legislative mechanisms to control shoreline development are most effective when applicants seek advance approval for their projects through a plan review process. This is not usually a problem for larger development proposals such as subdivisions or for severances which require municipal approval. However, it is more difficult to control small shoreline alterations such as beach improvements and dock construction, where property owners may be reluctant to approach government, or are simply unaware of the process. We **recommend** that:

FISHERIES POLICY BRANCH INTENSIFY ITS EFFORTS TO PROVIDE CLEAR DIRECTION, GUIDELINES, AND POLICY FOR THE EFFICIENT APPLICATION OF THE FEDERAL FISHERIES ACT AS THE PRIMARY LEGISLATION FOR MANAGING FISH HABITAT IN ONTARIO

OMNR CONTINUE TO SEEK RESTITUTION FOR, AND RESTORATION OF, DEGRADED HABITAT THROUGH THE FISHERIES ACT, THE PUBLIC LANDS ACT, AND THE LAKES AND RIVERS IMPROVEMENT ACT

OMNR DEVELOP INITIATIVES TO MAKE MUNICIPALITIES AND DEVELOPERS AWARE OF THE MINISTRY'S PRIORITY INTEREST IN LAKE TROUT LAKES AND THE SENSITIVITY OF LAKE TROUT LAKES TO DEVELOPMENT

OMNR DEVELOP AND COORDINATE A PROGRAM TO MAKE DEVELOPERS AWARE OF APPROVAL PROCEDURES AND THEIR LEGAL OBLIGATIONS

Within OMNR, the direction for resource management is given in strategic planning documents. In Northern Ontario, these are the Strategic Land Use Plans (SLUP), in Southern Ontario, the Coordinated Program Strategy (CPS). These documents establish very broad program objectives and targets. More specific guidelines are given in District Land Use Guidelines (DLUGs), District Fisheries Management Plans (DFMPs), and Timber Management Plans (TMPs).

Planning documents should incorporate the application of an ecosystem approach - an holistic concept based on an understanding of the linkages between species, communities and their environments. Species cannot be managed in isolation from one another, because species interactions and management actions can have an effect throughout the ecosystem. Humans are an integral part of the ecosystem; not external to it.

The Ministry's integrated resource management (IRM) approach, which requires program coordination to minimize conflicts and which embraces the concept of multiple and sequential use, should provide a satisfactory framework for managing aquatic ecosystems. The preparation of resource plans, their review and the subsequent monitoring of the effects of resource management decisions are the essential vehicles for delivering and evaluating program integration. Timber operations, access roads and other land use dispositions are planned according to environmental legislation and IRM procedures which are designed to protect other resource values and interests. We **recommend** that:

> **OMNR PLANNING DOCUMENTS EXPLICITLY IDENTIFY LAKE TROUT LAKES AS A RESOURCE OF PROVINCIAL PRIORITY, WARRANTING FULL PROTECTION FROM ADVERSE ENVIRONMENTAL IMPACTS**

DFMPs are prepared in the context of provincial goals, policies and strategic planning documents (e.g., SPOF II) and translated at the local district level into quantifiable fisheries management objectives. Proposed actions or tactics pursuant to these objectives are tailored to meet local needs and interests through a mandatory and extensive public involvement process. These plans are reviewed every five years.

The development of DFMPs has been extremely useful. Many innovative ideas about lake trout management have been presented in these plans. However, diverse approaches to common problems have given rise to "patch-work" management which is often difficult to rationalize, particularly when an action is regulatory in nature. While different approaches are sometimes necessary to account for unique resource issues or regional differences in social values and user interests, more coordination is required. There is a need for a dynamic, strategic process which is responsive to local public needs and allows for effective provincial coordination and consistency. We **recommend** that:

> **THE DISTRICT FISHERIES MANAGEMENT PLANNING PROCESS BE REVIEWED AND MECHANISMS BE DESIGNED TO IMPROVE THE DEVELOPMENT AND COORDINATION OF MANAGEMENT INITIATIVES, INCLUDING THOSE FOR LAKE TROUT**

Within OMNR, provincial fisheries policy initiatives are developed through a formalized committee structure. Draft policies developed in Main office and the field are submitted to Fisheries Policy Branch for review and approval. Those approved are then sent to various corporate policy and planning committees for further review. Depending on the nature, sensitivity, and scope of the draft policy, the Minister may decide to approve the policy immediately, or send it to other agencies and interest groups for comment. Policy proposals are also subject to review by the Ontario Fisheries Advisory Council (FAC). The council, comprised of interest group representatives and private citizens, meets regularly to review the fisheries program of the Ministry and makes formal recommendations directly to the Minister of Natural Resources. The Minister replies to these recommendations in a formal, public document. Some policies, such as SPOF II, require Cabinet approval.

Because of the commitment to thorough review and extensive consultation, the process of policy formulation is often protracted. On the other hand, the strength of the process is the generation of sound resource management policies which present a rationale and common focus for management which strengthens OMNR's position in negotiations and in potentially adversarial situations such as OMB hearings. We **recommend** that:

> **THE POLICY PROCESS BE FULLY UTILIZED AS A MEANS TO PROTECT LAKE TROUT LAKES IN ONTARIO, INCLUDING THE EXPLORATION OF A FORMAL POLICY STATEMENT UNDER THE PLANNING ACT**

Current targets assigned to the fisheries program are more closely aligned with resource use and extraction (e.g., number of fishing opportunities, kg of fish harvested) than with resource protection (e.g., number of spawning populations protected). The focus of these annual targets should reflect conservation needs. We **recommend** that:

> **FISHERIES MANAGEMENT TARGETS EMPHASIZE CONSERVATION OBJECTIVES**

It is also vitally important that Ministry fisheries initiatives have widespread public support. Municipal governments, Conservation Authorities and special interest groups such as the Ontario Federation of Anglers and Hunters (OFAH), the Northern Ontario Tourist Outfitters (NOTO), the Federation of Ontario Naturalists (FON), and the Federation of Ontario Cottager's Associations (FOCA) are all interested in resources, but their agendas do not always coincide, nor agree with that of OMNR. The local affiliates of these groups and the public in general often promote "quick-fix" short-term management actions which rely heavily on expensive technological solutions. Also, these groups often voice strong and diverse opinions about the management of fisheries in their immediate area which can make the decision-making process complex and unusually lengthy. For example, from conception to promulgation into law, it may take more than two years to effect a regulation change. While public review and consultation ensures that proposed management actions have broad acceptance, these actions can be diluted by the process, making them more palatable socially, but less effective biologically. The resource is invariably the loser. To address these impediments to effective fisheries management, the Ministry needs to better communicate the ecological principles on which the management of aquatic ecosystems is based. We **recommend** that:

OMNR IMPROVE THE UNDERSTANDING OF ITS CLIENTS ABOUT THE OBJECTIVES AND PRINCIPLES OF SUSTAINABLE RESOURCE MANAGEMENT

Regardless of the need to improve its science transfer responsibilities, it must be understood that the first allocation priority is to resource maintenance (OMNR 1978a); that is to the perpetuation of the resource. This priority must be accepted by all user groups before allocations can be made to any user group. A long-term view, which emphasizes, as a first priority, the inherent natural production limitations of ecosystems must be adopted. We **recommend** that:

OMNR PLACE MAJOR EMPHASIS ON ALLOCATION STRATEGIES WHICH ENSURE LONG-TERM MAINTENANCE OF THE RESOURCE

EXPLOITATION

OVERVIEW

The lake trout is a highly desired species which is vulnerable to exploitation. Both angling quality and fish stocks can decline substantially with only a moderate amount of fishing (MacKay 1956; Eschmeyer 1964). The vulnerability of lake trout to exploitation (and also other stressors) is related to its low reproductive potential, slow growth, late maturity, and slow turnover or replacement rate. On a province-wide basis, exploitation is the most critical stress affecting the lake trout in Ontario (Olver 1988; Lewis et al. 1990).

Sport fishing surveys generally have shown that while the opportunity to catch fish is important, the number and size of the fish caught are relatively unimportant compared to other values. For example, a Department of Fisheries and Oceans (DFO) survey (DFO 1988) concluded that of the 11 most important factors affecting the enjoyment of angling, the first six related to the environment, rather than the actual capture of fish. The preservation of environmental quality of lake trout lakes will help to meet the needs and expectations of many Ontario anglers for a high quality environment and the opportunity to catch lake trout. Nevertheless, one of the difficulties in managing lake trout is reconciling traditional social values - anglers enjoy eating the lake trout as much as they enjoy its sporting qualities.

In the southern part of the province, lake trout lakes are situated close to urban centres and are easily accessed. Retired or seasonally unemployed anglers often account for heavy angling pressure during the winter months. In these areas, the harvest of lake trout can easily exceed annual production. In many lakes, the quality of the lake trout sport fishery has been seriously eroded, the catch rate is low, and the probability of catching a large trout is very small. Even so, many anglers seem content with catching and retaining lake trout measuring only 30-40 cm in length.

Generally, lake trout stocks are in better condition in northern Ontario because demands on stocks have been less, but a decline in angling quality is evident in some northern areas. An

expanding network of logging roads has increased access to lake trout lakes. A well developed tourism infrastructure depends on the fisheries resource. Main base lodges, outpost facilities, and commercial boat caches provide a mix of different services, mainly to non-resident clients. Many of these operations depend on high quality angling opportunities to attract business. Most of the operations have been oriented to open water fishing, but some tourist operators are beginning to provide all-season accommodation and services. Assuming that the demand for angling opportunities and access will increase, the loss of quality angling will become more widespread.

Whereas the fragile nature of the lake trout has been publicized widely by the Ministry, the control of exploitation has not kept pace with the growing demand for this species. With anglers having increased leisure time and more disposable income, the sport fishery for lake trout can be expected to continue to expand. Recently, there has been a tendency to reduce daily limits and manipulate winter seasons to offset this growing demand. It is now recognized that there is a considerable variation in productivity and sensitivity to exploitation among lake trout waters, particularly as it relates to lake size or surface area, and that existing harvest controls usually apply over broad areas (e.g., divisions) and are ineffective in preventing overexploitation (Olver 1988). For example, anglers are permitted to legally keep two or three lake trout per day and are entitled to do so for the better part of a nine month season on about 80% of the lake trout lakes in the province (Olver 1988). These regulations are difficult to reconcile with the fact that the annual sustainable yield may be removed in only a small fraction of that time on many lakes. Regrettably, the same rules (daily creel limits, seasons) usually also apply to lake trout lakes undergoing rehabilitation.

Management for sustained yield, in which annual harvest does not exceed annual surplus production, is a first principle of resource management. Anglers, however, often have difficulty in appreciating the significance of their own catch relative to total harvest (Christie 1978). Also, on lakes that have already been overfished, residual fishing pressure may prevent stock recovery (Christie 1978; Loftus et al. 1978). When demand exceeds supply, the guiding principle of sustained yield is too often regarded as an interesting but unimportant principle of fisheries management, rather than a standard practice.

The principle of sustained yield is based on the fact that the carrying capacity - the amount of fish that a waterbody can produce and sustain - is finite and fixed by solar inputs and the innate chemical, physical, and biological parameters unique to each waterbody. This concept is poorly understood by the public. Anglers generally have unrealistic expectations about the amount of production to be expected from self-reproducing stocks. Many anglers believe that the stocking of hatchery-reared fish will overcome what they perceive to be nature's "shortcomings" and that "quick-fix" or "band-aid" solutions, such as stocking, are all that is needed to restore degraded populations or create better quality fishing.

Stocking of fish cannot increase the natural carrying capacity of a waterbody. Stocking beyond this level, however, can increase the numbers and the biomass of the harvestable population in the short term, as in a put-and-take fishery. As anglers generally make little or no distinction between naturally and artificially maintained populations, this engenders unreasonably high expectations among anglers about the productivity of aquatic ecosystems. Stocking can significantly reduce the chances of restoring a fish stock where exploitation is high and, moreover, can have serious consequences for the genetic integrity of wild stocks. The principles of sustained yield and carrying capacity need to be better understood and more rigorously applied by managers if fish stocks are to be managed successfully on a renewable basis.

Some aspects of exploitation control can be addressed by changing management regulations to adjust to, or to counter improvements in fishing technology (Regier and Loftus 1972). Christie (1978), however, warned that traditional harvest control regulations such as catch limits, size limits, and closed seasons only work well when supply exceeds demand and when angling pressure is evenly distributed across the resource base. Hence, as demand increases, reliance on just these techniques generally results in mediocre fisheries. Recent innovative approaches to harvest control such as catch-and-release, slot-size limits, and gear restrictions are attempts to reduce overall harvest to achieve a balance with production, without reducing fishing opportunities.

Overharvest can be controlled by limiting fishing opportunities, limiting harvest, or by restricting access to the resource. Ideally, managers should first examine harvest reduction tactics which protect angling opportunities. Significant reductions in seasons and possession limits to solve overexploitation problems are often not willingly accepted by anglers. Some, and perhaps most of this resistance may be overcome by raising the level of awareness of the problems and solutions to overfishing among the users of the resource. Access controls are also not popular, as they are viewed as an infringement of travel "rights" on Crown land.

Political and bureaucratic reluctance to change is also encouraged by the insistence of organized client groups that the Ministry should "manage the resource not the user". Yet, lake trout harvest is primarily determined by the amount of fishing (Goddard et al. 1987; Evans et al. 1991a). Thus, harvest can best be controlled by regulating the users. In a more holistic sense the view that humans, as the top predators, are an integral part of the ecosystem is gradually becoming more widely accepted as a tenet of renewable resource management.

Client groups are often reluctant to support additional harvest and effort controls for lake trout, unless there is an identifiable overharvest problem on a specific lake. Although managing lakes on a case by case basis seems a reasonable strategy, this type of management is very expensive and it may not be a practical approach, at least on a widespread basis. In areas of the province where exploitation pressures are high, a proliferation and fragmented array of locally initiated regulations has evolved, largely in response to overharvest problems on a lake by lake basis. Such diverse actions often confuse the public and fail to deal effectively with exploitation over the long term.

Lake specific controls can also have a negative impact on adjacent trout fisheries as angling pressure is often simply shifted to nearby areas. Furthermore, as the number and complexity of regulations increases, it becomes more difficult to rationalize different approaches from a biological perspective across jurisdictional boundaries. Martin (1966), in his review of various management practices in Algonquin Park lakes concluded that "what is biologically ideal for each of the fisheries will always have to be tempered by what is administratively feasible for the

fisheries as a whole".

More attention needs to be focused on the values that constitute "quality" fishing. There is no consensus about what types of fisheries anglers desire, nor are there harvest-quality standards by which the status of such fisheries may be measured. A major shift in philosophy is required, both by government and sport fishermen, towards managing for quality recreational angling opportunities within the natural carrying capacity of a lake, with much less emphasis on the kill.

EFFORT AND LAKE AREA EFFECTS ON HARVEST

Overexploitation is "a rate of fishing and fish removal that causes a change in the abundance of mature fish sufficient to lower the natural productive capacity below that required to achieve optimum yield" (Evans et al. 1991a). As stated earlier, overharvest by anglers is the most critical stress affecting inland lake trout populations in Ontario (Olver 1988; Evans et al. 1991b). This stems from the fact that fish are a common property resource. There is a long standing tradition of unrestricted access to recreational fishing opportunities; a situation sometimes referred to as "free-for-all" fishing. This has been a significant constraint to effective control of lake trout harvest and has fuelled the need for increasingly stringent regulations designed to limit harvest indirectly. Nevertheless, these regulations have been largely unsuccessful in controlling angler harvest of lake trout and may well continue to be ineffective as long as angling effort remains inadequately controlled.

Angling effort is the primary determinant of harvest. Using simple correlation analysis, Goddard et al. (1987) and Carl et al.(1990) found that effort accounted for 73% and 72% of the annual variation in harvest by weight. Effort and harvest also show important seasonal and lake area effects. Large lakes produce more and bigger lake trout than small lakes and are, therefore, capable of supporting larger fisheries. On a per-unit-area basis, however, effort and harvest, expressed as fishing intensity and yield, are greater on small lakes (Payne et al. 1990; Evans et al. 1991a). On small lakes, yield of lake trout was also much greater in winter than in either spring or summer (Evans et al. 1991a). For all lake sizes, yield during the winter was similar to the open-water fishery (spring and summer combined) even though the open-water season is

much longer and the fisheries capture larger fish (Evans et al. 1991a).

The potential yield of lake trout is limited by available habitat and may be estimated from a quantitative measure of that habitat (Christie and Regier 1988). Both thermal habitat volume (THV) and lake area provide reliable predictions of potential yield (expressed as harvest - H) of lake trout. The equation describing thermal habitat volume (Payne et al. 1990) is as follows:

$$\log_{10}H = 2.15 + 0.714\log_{10}(\text{July THV}) \quad (r^2 = 0.97)$$

where H is the annual lake trout harvest in kg and July THV is the volume of the lake between the 8 and 12°C isotherms in July. The strength of this formula lies in its biological basis, as the carrying capacity is determined by the amount of suitable habitat (that portion of the lake volume with appropriate temperature and oxygen regimes). We **recommend** that:

THE THV FORMULA BE USED TO CALCULATE THE MAXIMUM POTENTIAL HARVEST OF LAKE TROUT IN ONTARIO LAKES

We caution that this formula estimates the *maximum* potential harvest of lake trout, as the equations were derived from relatively productive lakes. The potential harvest from most Ontario lake trout lakes would be lower than predicted by Payne et al. (1990). Moreover, the authors stated that the confidence limits about this regression are quite large and may approach an order of magnitude for estimates of annual harvest.

The thickness of the thermal habitat volume is reasonably constant among "good" lake trout lakes and THV is proportional to lake area. Hence, lake area is a reasonable surrogate for THV if reliable temperature data are unavailable. When temperature data are not available, the following formula from Payne et al. (1990) describes the relationship between lake area (A) in ha and annual harvest (H) in kg:

$$\log_{10}H = 0.500 + 0.830\log_{10}A \quad (r^2 = 0.92)$$

Again, this Payne et al. (1990) equation is derived from essentially larger and relatively productive lakes and, thus, provides an estimate of the *maximum* potential harvest of lake trout.

Evans et al. (1991a) developed a similar equation based on a larger data set that may well be more representative of Ontario lake trout lakes in general. The Evans et al. (1991a) equation provides a lower potential harvest of lake trout than the Payne et al. (1990) equation and reflects the inherent lower productivity of the lakes in their data set. As the Evans et al. (1991a) equation is based on a larger, more representative data set and as it provides a more conservative estimate of potential harvest, we **recommend** that:

THE EQUATION $\log_{10}H = 0.60 + 0.72\log_{10}A$ BE USED TO CALCULATE THE POTENTIAL HARVEST OF LAKE TROUT FROM LAKE AREA

The Payne et al. (1990) THV equation and the Evans et al. (1991a) lake area equation predict different potential annual harvests of lake trout. While this seems inconsistent, the THV equation estimates the *maximum* sustainable harvest and, therefore, establishes the upper limit for lake trout harvest. By comparison, the Evans et al. (1991a) lake area equation provides a more conservative estimate of potential lake trout harvest. The difference between the two estimates thus reflects the difference in the inherent productivity of lake trout lakes in Ontario.

The thesis underscoring annual productivity estimates derived from the morphoedaphic index (MEI) (Ryder 1965) was that differences in mean depth and total dissolved solids reflected differences in lake productivity at the fish community level. The MEI was not intended to predict potential fish production for individual species. Carl et al. (1990), for example, demonstrated that MEI is not a sensitive enough indicator to reflect productivity changes within Ontario's lake trout lakes.

When observed yields are compared to potential yields as an indication of stress, particularly overharvest, stressed lakes will generally have reduced yields, i.e., below the potential yield. (In surplus production models the yield can lie on either side of the MSY point on the curve, depending on the amount of effort.) Consequently, the comparison of observed yield to potential yield alone cannot be used to determine the status of a lake trout population.

Evans et al. (1991a) found that annual fishing intensity (rod-hrs ha^{-1}) in what they termed small lakes (<500 ha) was 2.5 and 4.6 times greater than in medium (501-2500 ha) and large (>2500 ha) lakes. They also reported that actual observed mean fishing intensity in winter was 4.8 and 2.1 times greater than in spring and summer and 2.6 times greater than in both seasons combined.

Yield varies with lake area and season. The data of Evans et al. (1991a) showed that the annual yield in a 100 ha lake would be expected to be 1.4 and 2.0 times larger than in a 1000 ha and a 10,000 ha lake, although the total harvest would, of course, be much smaller. The following is a comparison of estimated mean annual yields (kg ha^{-1}) from Evans et al. (1991a) based on inland Ontario lakes adjusted to a lake area of 100 ha, 1,000 ha and 10,000 ha, with the yield estimated from a similar equation derived by Payne et al. (1990), for a selected group of lakes at or near MSY:

	AREA (ha)		
	100	1,000	10,000
Evans et al.	1.05	0.74	0.52
Payne et al.	1.44	0.98	0.66

The estimated annual yields from Evans et al. (1991a) are below similar estimates for selected lakes having maximum sustainable yields as predicted by Payne et al. (1990). This implies that Ontario lake trout lakes in general: are being harvested near their potential but have lower inherent productivity than predicted by Payne et al. (1990); or have been previously overharvested and are producing below their potential. This is suggested by the analyses of Lester et al. (1991). Figures 4 and 5 show that the vast majority of the 78 self-sustaining lake trout lakes in their data set have CUEs that are below the reference value associated with maximum sustainable harvest. These lakes either have lower productivity, or are in the overdeveloped-late and recovery stages of development. In either case, this suggests that harvests of lake trout generally need to be reduced in Ontario to protect less productive lake trout stocks and to allow overexploited stocks to recover.

Evans et al. (1991a) suggested (essentially as a guideline for comparative purposes) that annual yields in excess of 0.75 kg ha^{-1} represented high risk and might be considered as an indicator of excessive harvest. Based on the THV maximum yield equation, the critical level of 0.75 kg ha^{-1} may be conservative in productive small and medium lakes, but it appears to be representative of lakes in the order of 10,000 ha.

Evans et al. (1991a) presented a number of diagnostic tools to assess the relative exploitation status of a *particular* lake trout population. By using these tools, managers can identify potential problems. Regressions of harvest (number and weight) on effort for different seasons of the year are given in Fig. 1-6 of Evans et al. (1991a). Similarly, regressions relating yield in number and weight to fishing intensity for different seasons are presented in Fig. 8-13 of Evans et al. (1991a). Weight is a more sensitive indicator of overharvest, as numbers would be expected to increase as the mean length and age decrease due to exploitation, whereas biomass will decrease when the theoretical MSY is surpassed (Evans et al. 1991a). The magnitude of the deviations from the fitted regressions in their figures indicate the degree to which a lake is producing a larger harvest or yield (positive) or a lower harvest or yield (negative) than other Ontario lake trout lakes at comparable levels of fishing. Evans et al. (1991a) suggested that large negative deviations may indicate lower than expected harvests or yields, or possibly lakes with low natural productivity, or lakes under stress. Large positive deviations might indicate either short-term excessive harvests and yields, or highly productive lakes if the levels are sustained. We **recommend** that:

> **THE DIAGNOSTIC TOOLS PRESENTED IN FIG. 1-6 AND 8-13 (EVANS ET AL. 1991a) BE USED AS FIRST ORDER INDICATORS OF THE RELATIVE EXPLOITATION STATUS OF LAKE TROUT POPULATIONS ON LAKES WHERE HARVEST DATA ARE AVAILABLE**

Under the sampling framework proposed by Lester et al. (1991), however, harvest data would not be collected by districts. In lieu of harvest data, they used estimates of annual effort and abundance (harvest weight per-unit-effort) to classify lake trout populations into various stages of fisheries development. However, their model was developed from only five productive lake

trout lakes and its use could produce misleading results for less productive lakes. We **recommend** that:

ADDITIONAL DATA BE ACQUIRED TO BROADEN THE SCOPE OF THE LESTER ET AL.(1991) FISHERIES DEVELOPMENT MODEL

Carl et al. (1990) presented a lake classification system based on lake surface area which could be used to categorize lakes from the standpoint of yield expectations. The greatest differences in fish community structure and lake trout yields occurred between the smallest (<256 ha) and the largest (>1024 ha) lakes in their classification system, with the smallest lakes having the fewest species and the highest lake trout yields. The presence or absence of all predators and coregonines was positively related to lake area; again with a major shift occurring within the range of 256 to 1024 ha. Within this transition zone (257-1024 ha), many of the characteristics of the lake trout community gradually change. They proposed a lake area classification system of small (<256 ha), medium (257-1024 ha) and large (>1024 ha) lakes.

In Ontario, most managers have expected yields for lake trout lakes, irrespective of size, to be in the order of 0.25-0.75 kg ha^{-1} (Martin and Olver 1980). The THV yield equation developed by Payne et al. (1990) suggests that higher maximum sustainable yields are possible on small and medium size lakes. This will have to be considered when determining what the upper limits to yield might be on an area basis for establishing "early warning flags". The use of the THV yield equation will also affect the lake areas selected for management purposes. Nevertheless, as the yield of lake trout varies with lake area, the use of a single annual potential yield of 0.75 kg ha^{-1} to identify risk to overexploitation should be replaced in the future with values based on lake area. Research into these subject areas must be conducted as a high priority as it will provide the requisite means to refine our management techniques and to improve the precision of lake trout specific yield equations. We **recommend** that:

OMNR CONDUCT FURTHER STUDIES ABOUT THE RELATION BETWEEN LAKE SIZE AND SUSTAINABLE YIELD

The analyses of Payne et al. (1990) and Evans et al. (1991a) clearly show that the winter fishery is the fishery most in need of stronger harvest controls. Payne et al. (1990) showed that the removal of a disproportionate amount of small, immature fish as occurs during the winter would have a negative effect on recruitment. In several jurisdictions, winter fishing for lake trout is more strictly controlled than it is in Ontario (Olver 1988). Restrictions on winter fishing for lake trout in Quebec have recently been announced.[1]

Payne et al. (1990) showed that small lakes are most at risk to overexploitation. They used 100 ha as an example of a "small" lake. Although smaller lakes have relatively higher productivity, total annual surplus production is low, and it can be easily removed in a few days or less of winter fishing (Ryder and Johnson 1972). This implies that a total closure to winter fishing may be necessary on "small" lakes. Even though our understanding of what constitutes a "small" lake is incomplete, we believe that a reduction in harvest on small lakes during the winter season is clearly necessary. We **recommend** that:

LAKE TROUT LAKES 100 HA AND LESS BE CLOSED TO WINTER FISHING

Evans et al. (1991a) regressed lake trout yield on lake area and determined that 1008 ha (95% confidence interval: 694-1463 ha) was the critical lake size in winter fisheries, wherein the lake trout yield exceeded one-half the annual yield (0.375 kg ha^{-1}). Although this relationship is relatively weak ($r^2 = 0.22$), nonetheless, it constitutes the best available science. As lake trout lakes are generally overharvested, a cautious management regime is warranted. Based on the analysis of Evans et al. (1991a), the absence of direct controls on annual lake trout harvest and the resultant need to control winter fishing, lakes less than 1000 ha should be subjected to regulations to reduce the amount of effort and thereby harvest. Some 87% of the province's lake trout lakes are <1000 ha in surface area and winter fishing for lake trout is only allowed on

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[1]The Province of Quebec has recently announced a ban on almost all winter fishing for lake trout in that province (H. Fournier, Ministere du Loisir, de la Chasse et de la Peche, 13 rue Buteau, Hull QC, J8Z 1V4, pers. comm. to C. Olver).

80% of all lake trout lakes in Ontario (Olver 1988). Hence, about 69% of the province's lake trout lakes would be affected by such a regulation change. Current winter seasons could be maintained on larger lake trout lakes (>1000 ha), as they may be able to accommodate an increase in angling pressure. We **recommend** that:

THE WINTER LAKE TROUT SEASON BE REDUCED ON ALL LAKE TROUT LAKES <1000 HA TO ONE MONTH (FEBRUARY 15 - MARCH 15)

EFFECTS OF STOCKING

During all seasons, the fishing intensity is greater on stocked lake trout lakes than on non-stocked lake trout lakes. Evans et al. (1991a) found that the mean fishing intensity on stocked lake trout lakes was 4.6, 1.4, and 3.1 times greater than on unstocked lakes during the winter, spring, and summer. This suggests that angling is heavily influenced by stocking. Evans et al. (1991a) discovered that the annual yields in both number and weight of lake trout are as high or higher from wild populations as from populations receiving supplemental stockings. However, in winter, more fish were taken in stocked lakes, but they weighed less than in unstocked lakes, indicating that stocked fish tend to be harvested at a younger age and smaller size than wild fish. Evans et al. (1991a) suggested that stocked lakes may be overharvested in winter, and that stocking simply maintains harvests of small, immature fish above the natural carrying capacity. Moreover, the harvest per-unit-effort by both number and weight was consistently lower in stocked lakes in all seasons.

ADDITIONAL HARVEST CONTROL TECHNIQUES

Recently, both Olver (1988) and Smith et al. (1988) have reviewed harvest control mechanisms and suggested regulatory strategies for lake trout in Ontario. Both reports are substantial contributions to the management of lake trout. Managers should be familiar with these reports.

To control overharvest, the *kill* of fish must be better regulated. This may be accomplished by: limiting fishing opportunities; imposing catch-and-release regulations; making anglers less efficient; or by implementing quota management. Fishing opportunities may be controlled by

manipulating the length of the fishing season, by limiting physical access to the resource, and through pricing measures. Pearse (1988) suggested that limited entry is an idea whose time has come - if we wish to preserve quality angling. Certainly the analyses by Payne et al. (1990) and Evans et al. (1991a) support the idea that entry to the lake trout fishery should be limited - either by restricting the number of participants and the amount of time they may pursue their sport, or by controlling the number and size of the fish killed - to ensure that fish stocks are not overharvested. Catch-and-release fishing requires that all or a portion of an angler's catch above, below, or between specified sizes must be returned to the water. Restrictions on fishing gear or methods may be used to reduce angling efficiency. Quota management implies that a specified maximum number of fish of a certain species may be kept by an angler in a year. This may refer to an angler's total catch from all lakes, or it may be lake specific. The intent of all these methods is to reduce the total mortality to levels which will allow natural reproduction to sustain fish stocks.

Payne et al. (1990) suggested that a total annual mortality (A) greater than 0.5 almost certainly indicates overexploitation, while an A of 0.45-0.5 represents a high probability of overexploitation. Modelling in Evans et al. (1991a) showed that the capacity of lake trout stocks to accommodate angling mortality varies with lake productivity. Given these concerns and the lack of precision in measuring mortality rates, even the lower value of 0.45 may be too high in some lakes. At the present time, we cannot say what a more conservative value might be. We **recommend** that:

> **FOR THE MAINTENANCE OF SELF-SUSTAINING LAKE TROUT STOCKS AND THE REHABILITATION OF PLANTED STOCKS, A TOTAL ANNUAL MORTALITY OF 45% BE USED TO IDENTIFY OVERHARVEST AND AS A CRITERION FOR ESTABLISHING REGULATIONS TO CONTROL OVERHARVEST**

Evans et al. (1991a) showed that effort and harvest are closely associated with lake area and fishing season. Season restrictions, especially in winter, would be most effective in managing exploitation pressures and reducing total mortality on the smaller lakes. This is the context in

which the first attempt at lake area management (restricting the winter season on lakes < 1000 ha and closing it on lakes < 100 ha) is made. However, without some form of limited entry, it is impossible for managers to control the number of participants, even with very restrictive seasons.

Fishing opportunities may also be controlled by limiting access to the resource. Access control measures are designed to limit or impede access to waterbodies (via access quotas, road closures), to restrict access of certain user groups (via snowmachine, outboard motor, boat cache, or crown land camping restrictions), and to limit development on remote lakes. They are often not popular with anglers because they may discriminate against certain groups of anglers (i.e., the young, the old, those with little time, money or equipment, etc.). As effort and harvest are determined by accessibility to the resource, access controls may be useful alternatives to additional restrictions on angling opportunities. Managers should be familiar with their potential uses. They must also be sensitive to the implications of such measures. But it must be kept in mind that regulations are, by their very nature and intent, discriminatory.

One form of access control that has not been employed in Ontario, although it has been used extensively and successfully in other markets is the concept of "pricing". It involves charging a premium for a quality product; in this case, to obtain high quality fishing. Given that a segment of Ontario's anglers would pay for such fishing experiences, pricing may be an effective method for protecting lake trout stocks in the future.

Methods which restrict fishing opportunities should not be discarded simply because they are not popular. Anglers must be responsible for their actions and understand that the management of self-sustaining populations should be based on the principle of sustained yield in which the message is: remove a portion of the interest; and none of the principal. If restricting fishing opportunities to reduce effort and harvest is neither preferable nor possible, managers and anglers have three choices: catch-and-release regulations; gear restrictions; and quota management.

A high survival rate of released fish is essential for catch-and-release fishing. With the exception of the occasional provision that no fish may be killed or kept, some form of size limit is an integral part of all catch-and-release regulations. Therefore, hooking/handling mortality needs to be known if size limits are employed. Regulations that minimize hooking mortality, such as artificial lures only (see Wydoski 1977 and Mongillo 1984 for extensive reviews), should be imposed when size-specific catch-and-release regulations are in effect. Olver (1988) reviewed the few studies which explored the factors affecting hooking mortality in lake trout. A study done by Loftus et al. (1988) showed generally low mortality (in the order of 15%) for lake trout caught between May and September in the Great Lakes. The only documented study of winter hooking mortality of lake trout (Dextrase and Ball, in prep.) showed an overall mortality of only 10%. The fish ranged in size from 24-41 cm and averaged 32.6 cm fork length. As corroborating evidence is required prior to the widespread use of size limits during the winter months, we **recommend** that:

ADDITIONAL STUDIES OF LAKE TROUT WINTER HOOKING MORTALITY BE CONDUCTED WITH PARTICULAR REFERENCE TO SIZE-SPECIFIC CONSIDERATIONS

Although size limits are designed primarily to control the harvest of certain size classes of fish, they also may be used to reduce harvest. Payne et al. (1990) found that the vulnerability of lake trout populations could be reduced by using "[minimum] size limits to delay the entry of year-classes into the fishery" and they provided a method for determining what the optimal size at entry to a fishery should be. Size and hence, the age of recruitment can be manipulated. Thus, size limits have important management implications. Payne et al. (1990) found that both the level of fishing mortality required to reach MSY (F_{msy}) and the level of fishing mortality just sufficient to drive the population to extinction (F_{ext}), increase with the recruitment of younger ages to the fishery. The difference (F_{ext}-F_{msy}) is a measure of the vulnerability of a population to overexploitation, perhaps even to catastrophic decline and extinction. The larger the difference, the greater the margin of safety. The difference increases rapidly with increasing lake size. They proposed a strategy of management first developed for marine fisheries by Gulland and Boerema (1973). Known as the $F_{0.1}$ strategy, it is defined as the level of fishing mortality (F) for which

the marginal increase in yield-per recruit resulting from a small increase in F is 10% of the marginal increase in yield-per-recruit that would occur in a lightly exploited fishery. In essence, an $F_{0.1}$ fishing policy returns a yield close to the MSY and with less attendant risk (Payne et al. 1990). We **recommend** that:

FISHERIES MANAGERS USE THE $F_{0.1}$ MODEL TO DETERMINE THE LENGTH-AT-AGE FOR SETTING MINIMUM SIZE LIMITS

The data requirements and methods are found in appendices C and E in Payne et al. (1990).

The maximum size of lake trout is correlated with lake area (Payne et al. 1990). Minimum size limits (as well as slot-size limits) are designed to protect brood stock and their use makes sense in large lakes with piscivorous stocks, in which the age to maturity is considerably greater than the age of entry or vulnerability to a fishery. Piscivorous stocks also tend to be numerically less abundant per-unit-area than planktivorous stocks and a minimum or slot-size limit to ensure that lake trout would spawn at least once before they can be legally retained is an appropriate management tactic. However, there may be little need to impose any type of size limit on planktivorous/benthivorous lake trout stocks, which attain a small maximum size in small lakes, and in which the age of recruitment to a fishery approximates the age of first maturity, thereby allowing substantial spawning escapement. In large lakes where lake trout have considerable growth potential, a maximum size limit may be used to manage for a "no-kill" trophy fishery in which all fish over a specified size must be released, or alternatively, only one fish over a specified size may be retained per angler per day or season. Release of the large, mature fish will help to maintain recruitment to supply a fishery for smaller fish.

Because of variability in growth rates, size limits should be determined for individual lakes or sets of similar lakes. The choice of minimum, maximum, or slot-size limits will depend on the fisheries objectives established for the lake (quality, quantity, trophy, etc.). As little is known about the effectiveness of size limits for lake trout, we **recommend** that:

THE UTILITY OF SIZE LIMITS FOR LAKE TROUT CONTINUE TO BE INVESTIGATED

Gear can be regulated to reduce harvest by decreasing the efficiency of individual anglers without restricting fishing opportunities. A wide array of activities or devices may be regulated, such as: artificial lures, hook size, number of hooks, barbless hooks, bait species, live vs dead bait, use of "high-tech" gear, and the number of lines. These kinds of regulations are also used to reduce hooking mortality and affect the size of the fish caught. We **recommend** that:

ANY REGULATIONS PERTAINING TO THE USE OF GEAR BE TESTED EXPERIMENTALLY BEFORE WIDE APPLICATION

In recent years, there has been a large increase in the use of sophisticated or "hi-tech" fishing gear. There is some evidence that their use by skilled anglers can substantially increase effective effort and thus catch (Olver 1988). Payne et al. (1990) cautioned that increases in effective effort brought about by technological change can have serious consequences. There is some evidence that effort is dependent, in part, on fishing success (Goddard et al. 1987) and stocking (Evans et al. 1991a). By attracting more anglers to a water body through increased catchability, especially when stock abundance is unchanged, the effects of technology can be compounded (Payne et al. 1990). As it may prove necessary in the future to consider measures to counteract the effect of high technology gear, we **recommend** that:

THE USE AND IMPACT OF "HI-TECH" GEAR ON LAKE TROUT STOCKS AND FISHERIES BE EVALUATED AS A ROUTINE PART OF CREEL SURVEYS AND THROUGH EXPERIMENTATION

The winter fishery, which has the largest effort and harvest, has the least effective fishery per-unit rod-hour-of-effort. This may be offset by the legal use of two lines during that fishery. Winter anglers use a mean of 1.58 rods per angler (Evans et al. 1991a) and this tends to compensate for the seasonal factors that reduce angling effectiveness during the winter fishery, by raising it to the level attained by the open-water fisherman. Evans et al. (1991a) reasoned that two rods per angler might be as effective as two independent rods in small lakes because fish

density and thus encounter rates would be expected to be higher in small lakes. Lester et al. (1991) found that, on average, the number of rods had no effect on catch rate. Effects are variable, however, and their results showed that in some small lakes (200-1000 ha) two rods doubled the catch rate. The use of two lines could have serious results in small lakes. Winter angling efficiency could be reduced on small lake trout lakes by allowing fishing with only one line. We **recommend** that:

ONLY ONE LINE PER ANGLER BE ALLOWED DURING WINTER FISHING ON LAKE TROUT LAKES

The intent of daily catch and possession limits is to provide an equitable distribution of fish amongst all anglers and to control the annual harvest of lake trout. In the latter sense, they are a form of quota management. However, because the number of anglers is not restricted, catch limits in effect do not control harvest. Seasonal or annual catch quotas, by which an angler is only allowed to keep a set number of lake trout for each season or year would further help to reduce effort and subsequently harvest. This principle is embodied in wildlife management and has been used successfully in some important coastal fisheries. Lake specific quotas, equivalent to the annual harvestable surplus, as instituted successfully in many of the ZECs (Zones d'exploitation controlee (zones where exploitation is controlled)) in Quebec, is a management technique that applies this principle.

Quotas could be set to reduce harvest. They could apply to individual anglers and cover a fishing season or entire year, or apply to specific lakes. For example, each angler could be allowed to keep a specified maximum number of lake trout each year. Anglers would then be required to apply a tag to each fish they keep, or punch or notch their angling licence and record their killed fish on the back of the licence (Olver 1988). To be effective, such a system would require that each angler could hold only one angling licence in any one year. Each licence would have a lake trout stamp which would have perhaps 10 numbers. Each licensee would be issued 10 tags (for example) with corresponding numbers and would be required to immediately attach a tag to each lake trout which was caught and kept. The advantage of such a system is that it does not take

away angler opportunities as anglers have a choice of whether to tag a lake trout or release their fish and save their tag for another day. We expect that a large number of small fish would be released, and that overall harvest across the province would be reduced. There would also need to be a daily catch-and-release limit. For example, if mortality of released fish is 20%, than 5 released fish would mean one death.

A tag system is not a panacea, because heavily fished lakes may still be overexploited and require individual regulations. Quotas could be applied to specific lakes, but this is probably only warranted with large or important lakes that require frequent monitoring and which have limited access. This apparent need might be tempered by the fact that large lakes are less likely to be overexploited. A lake specific quota could also be employed through some form of lottery in which only successful applicants could keep a predetermined maximum number of fish. Fishing opportunities would not be reduced as all other anglers could fish, but their catch of the species under quota would have to be released. We **recommend** that:

THE FEASIBILITY OF IMPLEMENTING A TAG AND QUOTA SYSTEM TO REDUCE LAKE TROUT EXPLOITATION BE INVESTIGATED

Although catch-and-release, gear restrictions, and quota management appear to be attractive alternatives to mechanisms that reduce fishing opportunities, little is known about their effectiveness in reducing the harvest of lake trout. We need to know more about hooking and post-release mortalities before we can be confident about widespread adoption of size limits. Gear restrictions need to be investigated to determine if they are effective in reducing angling efficiency, or if they just have a cosmetic effect. Quota management has social consequences which need to be evaluated. All aspects of these harvest control mechanisms need to be tested.

Quebec has a great diversity of fisheries management approaches. The province is divided into areas of unrestricted access which are open to all anglers and subject to general regulations and areas of restricted access. The areas of restricted access include parks and reserves which are administered by the government, leases which are areas rented to lodge owners or outfitters,

private lakes and rivers which are managed by private groups or angling clubs and ZECs.

ZECs are a rather unique concept of fisheries management that evolved as the large private fishing leases in Quebec were cancelled. A typical ZEC might cover an area of 100 to 1200 sq. km, have 800-1500 members, and a Board of Directors. The board determines the management prescriptions, and usually hires a foreman who runs the day-to-day operations; looking after the collection of fees, the collection of biological information, and road construction and maintenance.

The government's involvement in fisheries management in the ZECs is through a written agreement with the Board of Directors. The goal of the government is to have each ZEC as a self-supporting enterprise. The guiding principle is to have each lake managed on a self-sustaining basis. Nevertheless, fish stocking is allowed within ZECs. The government dictates the maximum fees which may be charged for fishing and completes a financial audit on each ZEC each year. Regulations within ZECs cannot be less restrictive than the regulations which apply to the unrestricted access areas.

The potential harvest for each lake within a ZEC is determined by the government. It is reviewed every two years. When the actual harvest reaches 80% of the potential harvest (based on information supplied by ZEC workers), government biologists are notified. They estimate when the lake will reach its potential harvest based on CUE and the mean weight of angled fish. The Regional Director, upon advising the local media, can close a lake with three days notice.

There are three attractive features of ZECs:

- They operate on a "user pays" basis;
- The public is very much involved as a partner in fisheries management; and
- Lakes can be closed to angling when the potential harvest has been taken.

However, there are a number of problems in administering the system. Some ZECs run smoothly, but many are plagued with "people problems" including arguments about which lakes to stock and which regulations to set. Government biologists, often called upon to settle arguments, feel that they have substituted people management for fisheries management. Detailed biological data are not collected, and thus allowable harvests (quotas) are crudely estimated. Most lakes within the ZEC system are based on single species management so that when the potential yield for a single species is achieved, the lake can be closed. This would create problems in lakes with a variety of species. Notwithstanding these concerns, we recommend that:

OMNR EXPLORE THE POSSIBILITY OF ESTABLISHING, ON AN EXPERIMENTAL BASIS, A MANAGEMENT MODEL BASED ON THE ZEC CONCEPT

HABITAT

OVERVIEW

Habitat: its protection, maintenance, and rehabilitation are vitally important issues in lake trout management. Lake trout are sensitive to changes in water quality and require clean, cool, well-oxygenated water for survival, growth, and reproduction. Because of their low reproductive rates, environmental stability during early life stages from egg incubation through the first year of life is essential. Furthermore, spawning areas which typically consist of gravel and cobble, must be clean and remain free of organic material, sediment, and vegetation.

Habitat degradation may be chemical or physical in nature and may be caused by a wide variety of human activities. Domestic and industrial pollutants which enter directly into the water or enter via airborne transmissions may add nutrients to lakes and rivers and help deplete oxygen, or may add toxic substances which can reduce growth rates, impair reproduction, kill fish outright, or render them unfit for human consumption. Lake trout habitat can be affected by road construction, dredging, filling, draining, water drawdowns and diversions, hydroelectric developments, and any type of shoreline modification (Evans et al. 1991b). These activities, alone or in concert, can reduce or eliminate lake trout populations.

Cultural eutrophication degrades water quality and is a significant stress affecting fish populations. Lake trout occur largely on the Canadian Shield, an area of shallow well-drained soils, which poorly assimilate nutrient inputs (mainly phosphorus). Non-shield lake trout lakes can also be affected by excessive nutrient input. Symptoms of man-induced enrichment that occur in lakes include: accelerated algal production; decreased water clarity; an increase in sedimentation and siltation on spawning beds; and oxygen depletion in the hypolimnion.

Another significant stress affecting lake trout is acid precipitation. Shield lakes are poorly buffered and are subject to acidification with attendant loss of fish populations, including lake trout (Beamish and Harvey 1972; Harvey and Lee 1982). The lake trout is one of the more sensitive species to acidification (Beamish 1976). Through the effects of acidification, Beggs et al. (1985) estimated that lake trout have become extinct in about 3% of Ontario's lake trout

lakes. They also estimated that an additional 12.5% of Ontario lake trout lakes are extremely sensitive to this stress.

Many perturbations such as water level drawdowns, nutrient enrichment, and siltation can affect entire aquatic ecosystems and have significant implications for the well-being of lake trout. However, the effects of these stressors are often very subtle and difficult to predict. The impacts may only be noticeable by following the effects on one or more generations of lake trout, or when the compounding effects make such impacts obvious.

Lake trout habitat is managed by preventing the loss or degradation of essential habitats, or through the restoration of habitat that has already been lost or degraded. Fish habitat protection has been given a renewed focus with the signing of the Canada-Ontario fisheries agreement and the development of the Memorandum of Intent to protect fish habitat. These agreements embody the concept of "No Net Loss" of fish habitat and have led to mechanisms which permit more effective application of the habitat-related sections of the Fisheries Act. While they strengthen accountability and responsibility for the implementation of these sections of the Act, they also serve as potentially powerful tools to ensure that both large and small developments include provisions for the protection of fish habitat. Moreover, local and provincial initiatives are being directed at education, inventory, and enforcement of fish habitat legislation.

The protection of lake trout habitat is also accomplished in several other ways. Dredge and fill activities conducted on shorelands require a work permit which is issued by OMNR under the authority of the Public Lands Act. Conditions to protect habitat are applied to those work proposals so that they can be monitored and enforced. Habitat is also protected during the preparation of Timber Management Plans (pursuant to the Class EA for Timber Management Activities in Ontario, under review) through the application of various guidelines (e.g. "Timber Management Guidelines for the Protection of Fish Habitat" and "Environmental Guidelines for Access Roads and Water Crossings") which are designed to protect critical habitat and water quality. The success of these approaches will depend on the Ministry's ability to communicate the need for work permits and to effectively check compliance with the guidelines and test the

guidelines for work conducted on shorelands.

HABITAT REQUIREMENTS

In Ontario, lake trout lakes typically undergo a period of summer thermal stratification during which there is a loss of hypolimnetic oxygen and a concomitant reduction in the amount of cold water habitat available to lake trout. This is a very complex phenomenon which influences species interactions, alters lake trout population dynamics, and impairs physiological function and behaviour. Both MacLean et al. (1990) and Evans et al. (1991a) found that the amount of natural reproduction in a set of Ontario lake trout lakes was positively correlated with the volume of late summer habitat, defined in terms of temperature and oxygen. MacLean et al. (1990) also demonstrated a relationship between the loss of lake trout habitat and reduced lake trout angling yield.

The rate at which oxygen is depleted from bottom water is accelerated in nutrient enriched environments. Evans et al. (1991a) concluded that reduced oxygen concentration in the hypolimnion, especially in the deep nursery habitat, significantly reduces natural recruitment of lake trout. Hence, the reduction and loss of summer habitat in lake trout lakes is of major concern in Ontario.

MacLean et. al. (1990) found that for all life history stages, lake trout are generally distributed below an upper temperature of 15°C and above a lower oxygen concentration of 4 mg L^{-1} oxygen. They referred to this volume of water as the useable habitat volume (for lake trout). Within this, a more restrictive volume with temperature and oxygen values of < 10°C and > 6 mg L^{-1} oxygen was referred to as optimum habitat by MacLean et al. (1990).

A well-oxygenated, summer, deepwater nursery habitat is crucial to the perpetuation of naturally reproducing lake trout stocks, because the size of this nursery habitat can have a profound effect on natural recruitment. Yet, it is this depth stratum that is most susceptible to the effects of nutrient enrichment. Evans et al. (1991a) found that the mid-summer depth distribution of juvenile lake trout was much deeper than that of sub-adults and adults, and that the temperature

strata (3- 7°C) occupied by juveniles was much lower than the preferred or optimum temperature of juveniles under laboratory conditions (10.2°C ± 1.1), or adults in the wild (9.5°C ± 1.1). They hypothesized that, as long as oxygen concentrations are suitable, deep water provides a refugium for juveniles from cannibalism by adults; otherwise they are forced to move to shallower depths where they are vulnerable to predation (cannibalism) by adult lake trout.

Oxygen appears to be the most important niche dimension of lake trout summer habitat. From published observations, Evans et. al. (1991a) estimated the mean upper (5.8 ± 0.5 mg L^{-1}) and lower (4.2 ± 0.6 mg L^{-1}) oxygen response thresholds for adults. The upper level is the "average oxygen concentration at which swimming activity initially increases in response to declining oxygen." The lower level is the "average oxygen concentration at which lake trout show an avoidance response". They concluded that any factor which causes a reduction in hypolimnetic oxygen concentration below the incipient response threshold would reduce the amount of both the adult and juvenile habitat, and thus the size of the native lake trout population. We **recommend** that:

THE USEABLE HABITAT VOLUME FOR LAKE TROUT, WITH PARTICULAR EMPHASIS ON DEEP-WATER NURSERY HABITAT, BE RECOGNIZED AS A SENSITIVE INDICATOR OF HABITAT SUITABILITY FOR LAKE TROUT AND BE FULLY CONSIDERED BY MANAGERS IN THE PROTECTION OF LAKE TROUT HABITAT

Evans et. al. (1991a) also reasoned that the critical aspect of late summer habitat is the absolute amount of vital nursery habitat (volume of water <6.0 mg L^{-1} and >2.0 mg L^{-1} oxygen), as well as its relative proportion to the useable habitat volume. They argued that deep-water nursery habitat is a more sensitive indicator of habitat suitability than adult habitat, because as its volume decreases, recruitment declines as a result of increased density-dependent, size selective predation and cannibalism. We **recommend** that:

RESEARCH ON LAKE TROUT HABITAT DESCRIPTORS SHOULD FOCUS ON DEFINING MORE PRECISE DIMENSIONS OF JUVENILE HABITAT AND ON RELATING THIS TO USEABLE HABITAT VOLUME

Further, we **recommend** that:

THE FOLLOWING DIAGNOSTIC KEYS BE USED TO ASSESS THE REPRODUCTIVE STATUS OF LAKE TROUT STOCKS AS THEY REPRESENT THRESHOLDS FOR EXTINCTION:

OPTIMUM HABITAT VOLUME IS <20% OF TOTAL LAKE VOLUME AND USEABLE HABITAT VOLUME IS <40% OF TOTAL LAKE VOLUME

>8% OF TOTAL LAKE VOLUME HAS A DISSOLVED OXYGEN CONCENTRATION FROM 2-4 mg L^{-1}

>19% OF TOTAL LAKE VOLUME HAS <2 mg L^{-1} OXYGEN

It must be emphasized that these diagnostic keys represent thresholds for extinction of self-sustaining lake trout populations. In this regard, they do not constitute "bottom line" acceptable conditions.

DEVELOPMENT CONTROLS

The problem of determining how much development can be permitted without causing environmental degradation is one of scale. A reduction in water quality and loss of habitat can be such a subtle and gradual process that its root cause may not be recognized. The process may not be evident; just the end results. Current environmental safeguards may not be adequate, as the existing data may not be extensive enough to accurately predict long-term effects of development on lake trout lakes.

Because the lake trout is an environmentally sensitive species, shoreline development on lake trout lakes may constitute "ecological roulette." In the broader sense, Abbey (1988) questioned contemporary concepts of economic development, describing unchecked growth as the "ideology of the cancer cell." In the global context of sustainable development, this view underscores the need for a cautious approach to development. Lewis et al (1990),for example, noted that many

of the important stresses that affect lake trout can be linked to the degree of development, in that development influences lake access, exploitation, and land use.

Society is beginning to recognize the social, environmental, and economic benefits that accrue from healthy ecosystems. Destruction of habitat, whether it be direct or incremental, the incursion of human activity, and the visual destruction of natural features diminishes the value society places on the environment. A new approach is needed which reflects changing public attitudes whereby it is expected that ecological attributes will be protected. As well, we should not to be caught in a mindset of protecting only the best or representative environments. Present management approaches would seem to result in incremental losses to the extent that the viability of a lake as a lake trout lake comes into question. There is no foolproof or obvious system for addressing cumulative degradation.

Arguments for the protection of lake trout lakes are not esoteric in nature. A cautious approach to development is partly a product of the concerns and philosophies noted above. However, the intrinsic value we assign to lake trout lakes is supported as well by concerns for the inability of the lake trout and other species associates to withstand man-induced impacts. In a province which claims well over 200,000 lakes, only 2200 or about one percent contain lake trout. Given the paucity of lake trout lakes relative to the total fisheries resource, it is appropriate to recognize that *all* lake trout lakes in Ontario have great inherent value. These deep, clear, cold and unproductive lakes are the full extent of the resource. We cannot create more. A significant number (5%) of lake trout stocks in the province are now extinct and many more are adversely affected by habitat degradation, exploitation, and species introductions (Lewis et al. 1990; Evans et al. 1991a,b). Loss of lake trout stocks means the loss of locally adapted gene pools.

To a large degree, the attractiveness of many lake trout lakes is related to their remoteness, inherent beauty, and the fact that they are lightly or not developed. The social, cultural, and aesthetic aspects associated with undeveloped lake trout lakes are perspectives which identify these resources as a unique part of Ontario's heritage. We feel that the moral obligation and biological arguments for protecting lake trout lakes are compelling enough to **recommend** that:

THROUGH POLICY, OMNR EXPLICITLY RECOGNIZE THE INTRINSIC VALUE OF UNDEVELOPED LAKE TROUT LAKES AS AN INTEGRAL COMPONENT OF ONTARIO'S NATURAL HERITAGE AND AS PART OF ONTARIO'S WILDERNESS EXPERIENCE

The cause and effect relationship between nutrient input from shoreline development and the loss of hypolimnetic lake trout habitat has been well documented (OMOE and OMNR 1977, 1980). However, the process of habitat loss is slow and insidious, thus difficult to quantify and control. Rehabilitation is also an inexact science, hence a first principle should be to prevent habitat loss. For example, there is a need to provide a margin of safety well above oxygen regimes that cause extinction of lake trout. Given the need to assiduously protect lake trout habitat, we **recommend** that:

OMNR DISTRICTS IDENTIFY THOSE LAKES WHICH ARE TO BE MANAGED FOR LAKE TROUT, CLEARLY IDENTIFYING THOSE ON WHICH NO FURTHER DEVELOPMENT WILL BE PERMITTED, AND THOSE ON WHICH PRIVATE DEVELOPMENT WILL BE PERMITTED WITH SPECIFIED CONDITIONS

CROWN LAND ON LAKE TROUT LAKES NOT BE DEVELOPED OR PATENTED FOR SEASONAL OR PERMANENT DWELLINGS WITHIN 400 m OF THE SHORELINE

The implications of these recommendations are far reaching (Table 1). However, many of these lakes are either in remote areas which currently do not have good road access, or are within the boundaries of some of the larger provincial parks (Algonquin and Quetico), and are unlikely to be developed.

The potential for conflict increases with the proportion of private (patent) land on a lake. Lakes with a fair amount of patent land generally have good road access and high demand for additional seasonal and permanent dwellings. Their scarcity and desirability have led to increased shoreline property values and to strong pro-development pressures. Controls on Crown land and new restrictions on subdivisions and severances (new lot creation) on lake trout lakes by both

Table 1. The distribution of lake trout lakes in Ontario by OMNR Region, showing the percentage of Crown land shoreline.

	Percent						
REGION	0	0-19	20-39	40-59	60-79	80-99	100
Northwestern	12	2	1	3	9	104	313
North Central	10	2	2	2	4	43	197
Northern	4	4	1	2	6	15	61
Northeastern	58	10	6	8	22	96	320
Algonquin	118	49	17	20	17	24	167
Eastern	11	13	4	7	4	13	13
Central/ Southwest	2	0	0	0	0	0	0
Total for all regions	215	80	31	42	62	295	1071
Percent in each category	12.0	4.5	1.7	2.3	3.5	16.4	59.6

OMNR and the Ontario Ministry of the Environment (OMOE) will further inflate these values. There will, therefore, be even greater pressures on managers to allow development. Until municipalities can incorporate these new restrictions into their official plans, strong opposition to these policies can be expected. It will test the resolve of the Ontario government.

HABITAT MODELS

Evans et al. (1991a) showed that to prevent extinction of self-sustaining stocks, oxygen concentrations in summer habitat for adult and juvenile lake trout must exceed 3.1 and 2.3 mg L^{-1}. As these are oxygen levels at which population extinctions occur for native stocks, the processes of recruitment failure and population senescence must begin at higher oxygen concentrations. Thus, habitat models concerned with development on lake trout lakes need to take into account the necessity of a buffer or margin of safety, well above these extinction values.

In southern Ontario, the Ministries of the Environment and Natural Resources currently use two models to classify lakes with respect to their sensitivity to nutrients. The model in use in OMOE's Southeastern Region predicts the effect of the addition of 100 kg phosphorous yr^{-1} to the volume of optimum lake trout habitat (the volume of water >6.0 mg L^{-1} oxygen and $<10°C$). Lakes which would lose 50% or less of their optimum habitat are classed as moderately sensitive, while lakes which would lose more than 50% are classed as highly sensitive. Development which would result in additional nutrient loads would be allowed to proceed, albeit with conditions, on moderately sensitive lakes, but would be opposed on highly sensitive lakes.

The other model, used in OMOE's Central Region to determine the effect of additional development on lake trout habitat, is the optimum habitat formula model (J. Beaver, OMOE, 7 Overlea Blvd., Toronto, Ont. M4H 1A8, pers. comm.). This model predicts the effect of the addition of known amounts of phosphorus from a proposed development on chlorophyll *a* concentrations, and uses these results as a surrogate for the loss of optimum habitat. The model assumes that a 10% increase in late-summer chlorophyll *a* concentration is equivalent to roughly a 2% reduction in optimum habitat. If the model shows that a proposed development will exceed this guideline, the application is refused by OMOE on the basis of an unacceptable change in water quality (a 10% or less increase in chlorophyll *a* concentration will not result in a visible impairment of water quality - i.e. a change in colour, turbidity, etc.). In addition, the model has two defaults. First, if the oxygen concentration is zero at any point in the hypolimnion (usually immediately adjacent to the bottom) at any time during the year, the proposal is rejected by OMOE. Second, if the optimum habitat is already 20% or less of total lake volume, OMNR will "flag" the lake for more detailed study.

The assumption in the application of both models is that some habitat can be sacrificed without impairing either the standing stock or annual production of lake trout. As the relationship between population size and various measures of lake trout habitat volume is not well understood, we need to develop these models further, and to investigate the relationship between nursery habitat volume and optimum habitat and useable habitat volume. Whatever method or model is adopted, the implications to development on lake trout lakes with private land, and in

particular on shoreline lot creation, will be extensive. We **recommend** that:

OPTIMUM HABITAT MODELS BE REVIEWED BY THE MINISTRIES OF THE ENVIRONMENT AND NATURAL RESOURCES AND A COORDINATED APPROACH BE ADOPTED AS PROVINCIAL POLICY FOR MANAGING DEVELOPMENT ON LAKE TROUT LAKES

SPAWNING HABITAT

Lake trout usually select spawning locations consisting of clean rubble, 2.0 to 20.0 cm in diameter, located in water depths between 0.1 and 5.0 meters and on windward shore areas (Martin and Olver 1980; Evans et al. 1991b). These sites represent unique environments which facilitate embryonic development from egg deposition through to early larval stages. As lake trout have a relatively low fecundity, high egg survival is very important. Lake trout must be protected from the deleterious effects of human activities because excellent water quality at spawning sites is extremely important for the maintenance of healthy lake trout populations. Cultural eutrophication and physical disturbances such as: dredging and filling; shoreline clearing (sedimentation); boathouse, dock, and breakwall construction; and damming can have detrimental impacts on spawning shoals (Evans et al. 1991b).

Whereas natural fluctuations in water levels do not appear to have long-term impacts on lake trout populations (Evans et al. 1991b), there are many lake trout lakes in Ontario in which deliberate overwinter drawdowns expose spawning substrate, thereby causing extensive egg mortality at these sites. Further, drawdowns may similarly impact the populations of lake herring or cisco (*Coregonus artedii*) and lake whitefish (*C. clupeaformis*), which might, in turn, reduce the size of the lake trout forage base. Ideally, drawdowns should be completed before the start of the lake trout spawning season and overwinter drawdowns should be prohibited. Given the requirement for hydroelectric generation and spring flood control, we **recommend** that:

AGREEMENTS FOR WATER DRAWDOWNS ON LAKE TROUT LAKES BE NEGOTIATED TO MITIGATE THE IMPACT ON SPAWNING SHOALS

FISH STOCKING AND SPECIES INTERACTIONS

OVERVIEW

The stocking of lake trout has been widely practised in Ontario. Lake trout are usually planted to: rehabilitate depressed stocks; introduce the species into "barren" lakes; or to maintain sport fisheries by supplementing existing self-sustaining stocks. Regardless of the purpose, stocking has been one of the major and largely unchallenged management techniques used to satisfy the ever-increasing demand for lake trout. About 500 lakes in Ontario have been stocked with lake trout (Lewis et al. 1990).

Although the stocking of hatchery fish has created some notable successes, Pearse (1988) recommended that it "should be used cautiously ..... with careful attention to possible biological and ecological effects" and that it should not be used to make up for "deficiencies in the management of natural stocks." He strongly supported the principle, which is also espoused in SPOF II, of management towards natural, self-reproducing populations. Cameron (1983) showed that a restoration-rehabilitation strategy was consistently more cost effective than a put-and-delayed take strategy. Both Scarnecchia (1988) and Eshenroder (1989) expressed concerns about artificial fisheries and their reliance on technological solutions to "solve" ecological problems.

The long-term effects of species invasions on fish stocks in the Great Lakes is well documented (Smith 1968, 1972; Lawrie 1970; Lawrie and Rahrer 1972; Christie 1974). The loss of lake trout - the chief keystone predator - after a long history of exploitive fishing practices and the invasion of the sea lamprey was, in turn, followed by the precipitous decline in abundance of several other species, particularly the lake herring and the complex of deepwater ciscoes (*Coregonus* spp.) - the main prey species of lake trout. The absence of predation pressure and competition provided opportunities for exotic prey species such as rainbow smelt (*Osmerus mordax*) and alewife (*Alosa pseudoharengus*) to colonize the Great Lakes and establish self-reproducing populations. As a result, fish community structure has been considerably altered. Some native fish species disappeared, while others have remained depressed or have taken several generations to regain their previous abundance. The destabilized nature of the fish communities has forced managers to be reactive rather than proactive.

Genetically discrete stocks of lake trout disappeared in lakes Michigan and Ontario and only two small remnant stocks remain in Lake Huron. The lack of appreciable natural reproduction of planted lake trout is, in part, due to the use of hatchery fish which are not genetically matched or behaviourally adapted to the local environments in which they are planted. Ihssen (1984) suggested that prospects for rehabilitation could be improved by matching the characteristics of the donor stock and its environment to the receiving environment. He also noted that it might be necessary to develop new genetic stocks to restore lake trout in degraded habitats.

Moreover, studies by Haskell et al. (1952); Plosila (1977); and MacLean et al. (1981), which illustrated the influence of genetics on the survival of lake trout, showed that the stock concept also applied to inland lake trout stocks. This has implications to Ontario's stocking program. The planting of hatchery-reared lake trout in lakes with naturally reproducing populations is a common practice, and inter-breeding of planted and native fish could lead to a loss of genetic fitness and eventual extinction of unique gene pools.

Magnuson (1976) noted that managing with exotics was essentially a "game of chance". Ryder and Kerr (1984) suggested that the application of various ecological concepts (realized niche, interactive segregation, dominance-subordinance and resource partitioning) could reduce this risk. Nevertheless, they concluded that the "probability for damaging an indigenous community is at least as great as that of enhancing it".

The lake trout is the species most frequently stocked in lake trout lakes in Ontario. Stocking objectives are outlined in the following four categories:

- Rehabilitation - the objective is to restore a seriously depleted native lake trout stock to its former abundance. Inherent in the word "rehabilitation" is the intent to recreate a naturally reproducing, self-sustaining stock that will eventually not be dependent on stocking;
- Range Extension - the objective is to introduce lake trout into lakes in which the species does not occur, but which have suitable habitat for lake trout;
- Supplemental - the objective is to augment the existing native lake trout population with hatchery fish to increase angler opportunities and harvest; and

- Put-Grow-Take - the objective is to stock small lake trout into lakes which have suitable environmental conditions for growth and survival, but no native lake trout, so that the stocked fish can grow to a catchable size and be harvested by anglers. Reproduction by stocked fish is not expected.

Interactions between the existing fish community and the planted lake trout can affect stocking success. In small lakes with abundant planktivorous lake trout, intraspecific competition probably accounts for poor returns (Purych 1977). On larger lakes with more complex fish communities, predation by species such as burbot (*Lota lota*) and large piscivorous lake trout and competition with lake whitefish, lake herring, and young native lake trout, can decrease stocking success (MacLean et al. 1981; Carl et al. 1990). Both Powell et al. (1986) and Gunn et al. (1987) noted that the success of stocked lake trout was strongly influenced by competition from the resident fish community, particularly coregonids. Stocking lake trout in the presence of healthy native lake trout populations often results in poor returns of stocked fish. However,there are many examples in which the initial introduction of lake trout into small lakes without lake trout and with comparatively simple fish communities has resulted in self-sustaining populations (Olver and Lewis 1977; Hitchins and Samis 1986).

GENETICS AND LAKE TROUT STOCKING

Stocking hatchery-reared lake trout in lakes with wild stocks can result in the alteration or loss of native, locally-adapted gene pools and their eventual replacement with the gene pool of the stocked fish (MacLean et al. 1990; Evans et al. 1991a). The process may occur through introgression (transfer of genes between wild and hatchery fish during the spawning season); displacement of wild fish from spawning sites; or through incremental numerical displacement which is accelerated by increased exploitation rates on wild fish (Evans et al. 1991a).

The stocking of hatchery fish into lakes with native populations can have several important effects (Evans et al. 1991a):

- an increase in the abundance of adults of hatchery origin;
- a greater number of lake trout harvested in some stocked lakes than in unstocked lakes, but in general, the weight of the harvested fish is smaller;
- reduced survival of wild juveniles due to competition with a large number of hatchery fish or predation by hatchery fish;

- a reduction in the number of wild fish in the population which is magnified as fishing pressure increases; and
- the replacement of wild stocks by less fit domestic stocks, due to extensive stocking.

Some amplification of the last two points is necessary to understand the risks associated with supplemental stocking. Evans et al. (1991a) has shown that fishing pressure is higher in stocked lakes. In such lakes, stocked fish can be replaced at will, as the fishery is not dependent on their reproductive success. Stocked fish do not need to be adapted to local conditions, as they spend the critical component of their life history (the first year) in the hatchery from which they can be stocked in numbers well in excess of the natural carrying capacity. On the surface, the fishery continues unabated, as long as stocking continues. The reduced genetic fitness of the stocked fish only becomes apparent if stocking is discontinued and the fish must pass through the critical phase of the life cycle previously spent in the hatchery.

Wild fish, however, are constrained by the natural limitations of the environment and in stocked lakes with high fishing pressure are removed at a faster rate than they can be replaced by natural reproduction (a process termed "recruitment overfishing"). Hence, wild fish are removed from the population at a disproportionately greater rate. Over time, the genetic variability of the population is reduced as wild fish are replaced by hatchery fish (Evans et al. 1991a).

Although the evidence for introgression in lake trout in the wild is circumstantial, it has been documented for other salmonids. Reduction in genetic diversity occurs in the hatchery through the inbreeding of domestic stocks and the use of a small number of donor parents during wild egg collections. Both domestic stocks and transplanted stocks exhibit a loss of genetic diversity. Studies have also shown that transplanted stocks exhibit poorer growth, survival, and reproduction than native stocks (MacLean et al. 1990).

Managers concerned with stock rehabilitation, therefore, should select the most appropriate stock. At the very least, they should ensure that hatchery stocks to be released in the wild are carefully selected to minimize the potential impact on existing, indigenous populations (Spangler

et al.1981). We **recommend** that:

STOCK SELECTION GUIDELINES BE DEVELOPED TO REVIEW THE GENOTYPIC AND PHENOTYPIC CHARACTERISTICS OF STOCKS UNDERGOING REHABILITATION

THE DONOR STOCKS REQUIRED TO MEET MANAGEMENT NEEDS ACROSS THE PROVINCE BE CLEARLY DETERMINED

Evans et al. (1991a) concluded that stocking of hatchery-reared lake trout into lakes with native lake trout populations provides relatively minimal gains beyond self-sustaining stocks and that the practice of supplemental stocking is a "major ecological threat to the viability of the species." They recommended that supplemental stocking should be discontinued, as did MacLean et al. (1990).

We would expand this concern to include some rehabilitation efforts. Districts often stock lakes which contain small populations of native lake trout and cite rehabilitation as the objective. Stocking these lakes with lake trout of different genetic origin probably works at cross-purposes to the objective. Rehabilitation would be better served by reducing the stressor(s) which are keeping the native population at a low level, thereby allowing the native population to gradually rebuild. Evans et al. (1991b) noted that 22% of the lakes which presently contain native lake trout have been stocked at least once with non-native lake trout. Protection of the stocks which have yet to be affected by hatchery stocking is paramount. In view of the considerable risks associated with lake trout stocking, we **recommend** that:

SUPPLEMENTAL STOCKING OF LAKE TROUT NOT BE PERMITTED

REHABILITATION STOCKING NOT BE PERMITTED IN LAKES WHERE NATIVE LAKE TROUT STILL EXIST, UNLESS NATIVE STOCKS ARE USED

STOCKING BE PERMITTED TO REHABILITATE LAKES IN WHICH THE NATIVE STOCK HAS BECOME EXTINCT, OR TO EXTEND THE RANGE OF LAKE TROUT

STOCKING BE PERMITTED IN THE FEW LAKES IN ONTARIO WHICH CAN BE LEGITIMATELY CLASSIFIED AS PUT-GROW-TAKE. ALL OF THESE LAKES SHOULD BE ASSESSED TO ENSURE THAT NATIVE STOCKS DO NOT EXIST

During rehabilitation, fishing mortality must be kept at a low level to allow restoration to occur. On inland lakes, where overexploitation of stocks can occur in a few fishing days, the only practical methods to control fishing pressure are to either close the fishery, institute lake specific quotas, or allow only catch-and-release fishing. On the Great Lakes and large inland lakes (e.g., Simcoe, Nipigon) where stocking may occur over a broad area and angler pressure may be more dilute, managers have more flexibility to manage on a zone by zone basis. However, the strategy of controlling fishing mortality is as important on the Great Lakes as it is inland. Managers must effectively monitor and control angling and commercial fishing harvests to ensure that total annual mortality (A) does not exceed 0.45 if rehabilitation is to be achieved (Payne et al. 1990). We **recommend** that:

INLAND LAKES WHICH REQUIRE REHABILITATIVE STOCKING BE CLOSED TO EXPLOITATION FOR LAKE TROUT UNTIL THE PROCESS IS COMPLETE

ALTERNATIVELY, A VERY RESTRICTIVE FORM OF CATCH-AND-RELEASE FISHING (NO KILL OF FISH) BE CONSIDERED

EXPLOITATION ON THE GREAT LAKES AND LARGE INLAND LAKES BE CONTROLLED AT A RATE WHICH IS CONDUCIVE TO REHABILITATION ($A < 0.45$)

The termination of supplemental planting as a routine management practice will not be readily accepted by anglers. Some anglers may not care about protecting wild stocks and their gene pools. Furthermore, the perception, particularly in south-central Ontario, will likely be that fishing will get worse. The only acceptable trade-off to protect both angling and wild stocks is the provision of a higher level of angler satisfaction, that is, a general improvement in angling quality. To accomplish this task, low kill, catch-and release regulations will be necessary.

While a move toward a non-consumptive status, similar to that which now partially protects the muskellunge (*Esox masquinongy*), may not be necessary to the same degree for lake trout, we **recommend** that:

OMNR CONTINUE TO PROMOTE CATCH-AND-RELEASE FISHING FOR LAKE TROUT

We believe that management for native stocks should endorse a philosophy of "wild and natural". Management of self-sustaining populations, rather than reliance on supplemental stocking as a panacea, is consistent with this philosophy.

INTRODUCTIONS OF OTHER SPECIES

The introduction of other species can have a marked effect on lake trout and on community interactions (Evans et al. 1987; MacLean et al. 1990). Some species have been introduced inadvertently, while others have been stocked deliberately to provide forage for lake trout, or as an alternate or additional species for angling. The consequences of these intentional introductions have usually not been foreseen, nor have the results been closely monitored by managers. They can have a significant impact on lake trout population dynamics, altering both growth and survival. While the cause and effect relationships are often obscure, especially in large complex systems such as the Great Lakes, Carl et al. (1990) showed that the number of predators and competitors in a lake can have a negative effect on the relative abundance of lake trout. MacLean et al. (1990) and Evans et al. (1991a,b) concluded that the impacts of introductions on lake trout populations are seldom positive.

In food-limited environments, managers have tried to enhance the growth of lake trout by introducing forage fish such as lake herring, rainbow smelt, and alewife, and invertebrates such as the opossum shrimp, *Mysis relicta*. These species have significantly altered the population dynamics of lake trout, through direct or indirect interaction at specific life stages.

Generally, smelt introductions pose a significant threat to lake trout stocks in inland lakes. The introduction of smelt in Minnesota lakes, for example, resulted in the decline of juvenile lake trout growth as a result of competition for food resources (Hassinger and Close 1984). In Ontario, smelt occur in about 187 inland lakes, including 63 with lake trout (Evans and Loftus 1987). They also now occur in some remote lake trout lakes in northwestern Ontario. In most of these lakes, the presence of smelt is the result of unauthorized or inadvertent introductions. An increase in growth rate and condition factor has been observed in adult lake trout following smelt introductions, but the presence of smelt in the diet has also been implicated in elevated concentrations of mercury in lake trout (MacCrimmon et al. 1983; Evans et al. 1991b).

Although managers are concerned about the effects of smelt on lake trout, Evans and Waring (1987), for example, did not attribute the recruitment failure of lake trout in Lake Simcoe to the introduction of rainbow smelt as the lake trout population collapsed before the invasion of that lake by smelt. However, recruitment failure of lake whitefish occurred in several lakes following the introduction of rainbow smelt (Evans and Loftus 1987). Rainbow smelt interact with a wide variety of species and by changing food web patterns and redirecting energy flow, cause major restructuring of fish communities (Evans and Loftus 1987). They recommended that rainbow smelt should not be introduced into lakes containing naturally reproducing cold- and cool-water species, such as lake trout and lake whitefish, and Evans et al. (1991b) recommended that smelt should not be introduced into any inland lakes.

The introduction of the lake herring to Lake Opeongo in 1948 had profound effects throughout that ecosystem (Martin 1970; Martin and Fry 1973). Prior to the introduction of lake herring, lake trout exhibited a significant depression in growth during the transition from a planktivorous to a piscivorous diet. After the introduction, the lake herring became the dominant food item in the diet of lake trout. The growth depression disappeared and the growth rate of lake trout increased (Matuszek et al. 1990). Martin (1970) found that the percentage of intermittent spawners declined from a high of 17% in the years 1937-48 to 2% in the years 1955-65, and that infertile lake trout were not found after 1960. Fecundity, egg size, and ovary weight increased with a subsequent increase in recruitment to the fishery. Offsetting this, age and size

at maturity increased and the percentage of immature fish in the sport fish catch increased substantially. This introduction also had negative effects on other species (Emery 1971; Martin and Fry 1973). As similar long-term effects might be expected to occur in other lakes, a cautious approach with the introduction of lake herring is needed.

In Ontario, walleye (*Stizostedion vitreum vitreum*) occur in 321 lakes which also have lake trout, or about 15% of the lake trout lakes in the province (OMNR unpubl. data). These lakes tend to be much larger in surface area than lakes where the two species do not co-occur (Johnson et al. 1977). This is expected given the relationship between surface area and the number of fish species in lakes (Barbour and Brown 1974) in which larger (and deeper) lakes afford more habitat diversity and reduce the potential for niche overlaps, thus increasing the likelihood that more species will exist in a lake. Although there is no strong evidence of a negative interaction between lake trout and walleye, Ryder and Johnson (1972) suggested that walleye should not be introduced into waters containing salmonids. Evans et al. (1991b) cautioned against introducing walleye into small lakes containing native lake trout, noting lakes in southeastern Ontario where lake trout disappeared after walleye introductions.

The smallmouth bass (*Micropterus dolomieui*) is native to many lake trout lakes in Ontario. It has also been introduced into lakes where lake trout are present. Smallmouth bass were introduced into Lake Opeongo, where they were first reported in 1928. Martin and Fry (1973) did not observe any detrimental effects of smallmouth bass on lake trout. Ryder and Kerr (1984) concluded that the compatibility of smallmouth bass and lake trout was predictable on the basis of present knowledge. However, Ryder and Johnson (1972), Martin and Fry (1973), and Ryder and Kerr (1984) all suggested that introductions of smallmouth bass have a negative impact on brook trout (*S. fontinalis*), which often occur with lake trout.

Unauthorized introductions of fish, usually in the form of "bait dumping", are the most difficult for managers to deal with. They are virtually uncontrollable and occur without any regard for ecological consequences. Regulations prohibit the use of specific fish species as baitfish in some locations in the province. There is also a general regulation which prohibits the unauthorized

transfer of fish from one body of water to another, but this is difficult to enforce with baitfish. These controls are limited and "nuisance" species continue to be introduced into lake trout lakes across the province.

Introductions have not been confined to fish. For example, *M. relicta* has been introduced into several water bodies in western North America, usually to increase the food supply of resident salmonids. Because of the disruptive effects of these introductions on the fish community, Lasenby et al. (1986) recommended that the introduction of mysids into lake trout lakes be prohibited, pending a review of their impact.

Li and Moyle (1981) noted that oligotrophic lakes are more sensitive or vulnerable to species introductions than eutrophic lakes and hence, introductions into these systems represent a considerable risk. Lake trout lakes are a limited resource and introductions of species other than lake trout should not occur. We **recommend** that:

NEW SPECIES NOT BE STOCKED INTO LAKE TROUT LAKES

THE USE AND POSSESSION OF LIVE BAITFISH IN LAKE TROUT LAKES BE PROHIBITED

COMMUNITY EFFECTS

Interactions between lake trout and other fish species affect lake trout population dynamics and lake trout harvest, but the types of interactions and the magnitude of the effects are not well understood - primarily because few estimates of absolute or even relative abundance are available for lake trout and other fish species. Nevertheless, some theories concerning community relationships are far enough advanced to warrant their use in lake trout management.

Ecological theory predicts that lake trout biology and yield will be affected by the presence of other fish species and by the size of their populations. However, community influences may be hidden by the much larger effects of angler-effort (Goddard et al. 1987; Carl et al. 1990; Evans

et al. 1991a).

Sampling methods which are independent of angler-effort are required to determine the effects of fish community on the yield and biology of lake trout. Carl et al. (1990) were able to eliminate this effect by using gill net data. They found that the CUE of lake trout, expressed as kg/100m, was negatively correlated with the total number of predators (r^2 = .47). The presence of burbot and northern pike (*Esox lucius*) had a negative effect on the CUE of lake trout (r^2 = .10 and r^2 = .14).

Carl et al. (1990) found a number of relationships between lake area and community dynamics. First, large lake trout lakes normally contain a larger number of fish species than small lakes. Carl et al. (1990) suggested that lake trout lakes greater than about 1000 ha in surface area have, in general, a complex fish community with several major species present and one to three predators, in addition to lake trout. The logical explanation is that large lakes, on average, offer more diverse habitats. Second, large lakes are more apt to be connected to large water courses which act as immigration routes. There is a positive relationship between lake area and lake trout size, presumably due to the greater availability of prey fish in larger lakes. The lake trout in these larger lakes attain a larger mean size and are primarily piscivorous. The yield of lake trout from large lakes is normally less than the yield of lake trout from small lakes, but their larger size enables them to provide a greater total harvest, and makes them less vulnerable to overexploitation.

Carl et al. (1990) noted that coregonines and large invertebrates indicate the type of food web present in a lake and what the potential yield might be. They also suggested that some of the variation among some parameters with the fish community types might be explained by further categorizing lake trout lakes by the presence or absence of coregonines and large invertebrates. The presence or absence of coregonines is routinely recorded in standard lake surveys, but the presence or absence of large invertebrates such as *Mysis* is seldom recorded and is not required. We recommend that:

THE PRESENCE OR ABSENCE OF LARGE INVERTEBRATES BE DETERMINED AS A STANDARD PRACTICE IN ONTARIO LAKE SURVEYS

In theory, small lakes should produce a greater weight of lake trout per unit area as, on average, small lakes have simpler fish communities and lake trout living in small lakes consume smaller food items which are at a lower trophic level. However, Kerr and Martin (1970) stated that lake trout use more energy in foraging for more abundant, but smaller organisms and they suggested that the two antagonistic processes may balance out and result in a relatively constant lake trout yield across a broad spectrum of prey size (and by inference lake size as particle size is related to lake area). However, Carl et al. (1990) argued that the trophodynamic theory suggested by Kerr and Martin (1970) may hold only for lakes with very small prey organisms. Lakes which have large invertebrates, such as *Mysis* [or *Pontoporeia]* may be able to produce higher yields than lakes which have either a larger or smaller prey size. The presence or absence of *Mysis* may be a key descriptive feature of lake trout lakes and explain some of the variance associated with trophic level effects in planktivorous lake trout stocks (Carl et al. 1990). The interrelationships among lake size, prey size and productivity of lake trout require further investigation. We **recommend** that:

PREDATOR-PREY DYNAMICS BE INCLUDED IN RESEARCH ABOUT FACTORS AFFECTING LAKE TROUT PRODUCTIVITY AND SUSTAINABLE YIELD

ASSESSING THE STATUS OF LAKE TROUT STOCKS

OVERVIEW

Fisheries managers have a difficult task evaluating the status of lake trout populations. This responsibility can seem overwhelming given the number of lakes in Ontario. Stocks are also affected by a multitude of stresses and the effects need to be identified so that if warranted, the most appropriate corrective measure can be selected.

In Ontario, all 2200 lake trout lakes cannot, nor need to be, monitored intensively. Given that similar fish communities respond to the same stressors in similar ways (Loftus 1976), the knowledge gained from the intensive study of a representative set of lakes can be applied to other lakes with similar fish communities. In this report, these are considered to be communities in which lake trout is the dominant species in the coldwater community. This comparative approach to fisheries management has been well established in Ontario since the 1970s where it is commonly referred to as the type-lake concept (OMNR 1978b).

In assessing the status of lake trout in a lake or sets of lakes, questions arise about what information is needed, what sampling methods to employ, and how frequently such information is required. The present lack of sampling standards for assessment of FAU and district lakes, however, constrains the management of these lakes using the comparative approach.

Cost-effective, yet reliable methods need to be applied to ensure comparability of information about the status and health of fish stocks. To ensure that scientifically valid comparisons can be made, the sampling framework for FAUs and districts must be linked. Indices can then be established for district lakes that are sensitive indicators of change, that can be estimated from point-in-time survey data, and can be derived from small sample sizes of fish to make timely and suitable decisions. For these indices to be effectively used by managers, they need to be compared to provincial reference values established by FAUs.

The continuity of data collection is also an important consideration in assessing the status of fish stocks. On long-term study lakes, Carl et al. (1990) noted that lake trout population data should

be collected on an annual basis. They suggested that time series of at least 10-20 years were essential to understand better the underlying mechanisms affecting lake trout populations.

In addition to establishing standard sampling protocols for FAU and district fisheries studies, models are needed to allow managers to simulate the response of lake trout populations to possible management tactics and to assess the relative health of lake trout populations. Two such models, the Lake Trout Management Support System (LTMSS) and the Ecosystem Health Index (EHI), are now available for managers. Each is discussed briefly in this report.

The province of Ontario selected assessment unit lakes based on fish community type (FCT) (OMNR 1978b). Carl et al. (1990) examined the utility of fish community type as a means of determining if differences occur among lake trout communities which might suggest that they should be managed differently. Their results are discussed briefly in this report.

SAMPLING FRAMEWORK

Lester et al. (1991) described two types of lake trout assessment programs: one for FAU lakes; and another for district lakes (i.e., all other lakes outside the FAU network). The primary concern is to ensure the comparability of information collected by FAUs and districts while recognizing the differences in sampling intensity. They proposed a linked sampling framework and a set of assessment methodologies which delineate and integrate stock assessment programs for FAUs and districts. Within the sampling framework, sport and index fishing are the primary sources of data, although commercial fishing offers an additional data source. Catch indexing would be on a seasonal basis using angling or index fishing data. Index fishing would be conducted using standard, small-mesh gill nets set in the littoral zone during spring. Sampling protocols which delineate fishing method and seasonal and spatial factors will ensure the comparability of information among lakes.

For FAUs, Lester et al. (1991) proposed standard methods to help reduce sampling error, determine sample size requirements and levels of precision. Such studies permit the development and testing of lake trout population models and provide insights for managers about how these

systems respond to stress. Lester et al. (1991) proposed reference values for effort, abundance, mortality, growth, and condition for districts to evaluate the status of their lakes.

In some cases, however, the reference values have been established from very little data. Thus caution should be used in this comparative approach. Consequently, more data need to be collected and analyzed to increase the precision of these reference values. It is evident that the ongoing assessment of FAU lakes will be expensive due to the frequency and precision of the monitoring that is required. The cost effectiveness of the FAU system will be apparent when clear linkages to district lake monitoring programs are in place.

The purpose of assessing district lakes is to measure the status of fish populations, including lake trout, in the most cost-effective manner for a group of lakes, not individual lakes (Lester et al. 1991). As the level of sampling conducted on FAU lakes is too expensive to be carried out on the much larger number of district lakes, smaller sample sizes and indirect rapid assessment measures are needed. That is, indirect measures of effort, abundance, mortality, growth, and condition are required to compare to the reference values generated and periodically reevaluated by FAUs. This should provide managers with a reasonable degree of "comfort" about the health of lake trout populations within the group of lakes. Harvest data are collected by FAUs, but not by districts because harvest surveys are too expensive to be done on large numbers of district lakes and there is no "shortcut" method for estimating harvest. Hence, there is no reference value for harvest in the sampling framework proposed by Lester et al. (1991).

Lester et al. (1991) proposed three sampling intensities for establishing priorities for monitoring district lakes: resource inventory; effort indexing; and catch indexing. Resource inventory provides a general description of the limnological properties of a lake, its fish community, and potential stressors. These types of surveys help managers set priorities for selecting lakes for additional study. Effort indexing is the second level of sampling and is required for each season in which fishing occurs. This provides an estimate of annual effort which can be compared to a reference value. Catch indexing, the third level of sampling, uses angling and index fishing data to establish indices of abundance, mortality, growth, and condition which are compared to

previously determined reference values. We **recommend** that:

OMNR ADOPT THE LESTER ET AL. (1991) SAMPLING FRAMEWORK THAT EMPHASIZES THE LINKAGES BETWEEN INTENSIVE MONITORING OF FAU LAKES AND EXTENSIVE MONITORING OF DISTRICT LAKES

This recommendation presupposes that:

A STANDARD ASSESSMENT PROGRAM FOR FAU LAKES BE ESTABLISHED THAT WILL PERMIT THE DEVELOPMENT AND TESTING OF LAKE TROUT POPULATION MODELS AND THE PERIODIC RE-EVALUATION OF PROVINCIAL REFERENCE VALUES FOR LAKE TROUT

TREND-THROUGH-TIME LAKE TROUT POPULATION DATA BE COLLECTED ANNUALLY FOR A MINIMUM OF 10-20 YEARS

THE PRIORITY FOR MONITORING DISTRICT LAKES BE BASED ON THE HIERARCHY OF RESOURCE INVENTORY, EFFORT INDEXING, AND CATCH INDEXING

A STANDARD DISTRICT LAKE MONITORING PROGRAM BE ESTABLISHED THAT USES INDIRECT RAPID ASSESSMENT TECHNIQUES TO DETERMINE INDICES WHICH ALLOW THE COMPARISON OF THEIR LAKE TROUT POPULATIONS AGAINST PROVINCIAL REFERENCE VALUES

DISTRICTS, WHERE APPROPRIATE, AND FAUs ADOPT THE SPRING INDEX FISHING METHOD DESCRIBED BY LESTER ET AL. (1991) AS THE CATCH INDEXING STANDARD FOR THE ASSESSMENT OF LAKE TROUT LAKES

REFERENCE VALUES AND INDICES

FAUs will be required to collect data about effort, abundance, mortality, growth, and condition and establish reference values for these variables. Districts would then undertake a minimal low cost assessment program to develop effort and catch indices for comparison with provincial reference values.

The indices include:

- Effort index (called midday activity count (MAC));
- Abundance indices (CUE & HUEW for angling, CUE for index netting);
- Mortality index (called mean length above 400 mm (ML400));
- Growth index (called age at 400 (A400)); and
- Condition index (a, b parameters in the equation $W = aL^b$).

Districts would not undertake intensive catch sampling programs. Rather, they would obtain abundance indices and fish for biological sampling from either spring gill netting or from anglers, whichever is the least expensive.

Effort

Traditional creel surveys too expensive to estimate angling effort on district lakes. To reduce sampling costs, Lester et al. (1991) recommended sampling during the middle of the fishing day. The estimator, referred to as the midday activity count (MAC), is premised on the observation that fishing activity changes in a predictable fashion during the day. Using equations in Lester et al. (1991), daily effort can be calculated from the MAC and expanded for an entire season and year. The latter, known as annual effective effort, is then compared to a reference value ($Effort = 155.7\ Area^{0.34}$) to classify lakes as high or low effort. Lester et al. (1991) showed a relationship between effort and lake area [and also for harvested weight-per-unit-effort (HUEW) as a measure of abundance], but these relationships were based on only the five lakes used to derive the THV *maximum* sustainable harvest equation (Payne et al. 1990). While the current reference value proposed by Lester et al. (1991) should be used, we recommend that:

DISTRICTS ADOPT THE EFFORT INDEX, MAC, AS A LOW COST METHOD FOR EVALUATING ANNUAL EFFECTIVE EFFORT

FAUs CONFIRM THE USE OF MAC AS THE MOST APPROPRIATE ESTIMATOR OF ANNUAL EFFECTIVE EFFORT

Abundance

Lester et al. (1991) proposed three catch indices to measure relative abundance. The angling statistics, calculated from anglers targeting lake trout, are catch per-unit-effort (CUE) and

harvest weight-per-unit-effort (HUEW). Equations for determining these indices are given in Lester et al.(1991). No relationship was found between CUE and lake area and Lester et al. (1991) proposed a fixed CUE of 0.20 fish ang-hr^{-1} as a standard for the reference value. The reference value for optimal abundance (in weight) is: HUEW = 0.036 Area$^{0.22}$. The third abundance index, calculated from index fishing, is the spring gillnetting CUE. At present there is no reference value for index fishing. While the current angling reference values proposed by Lester et al. (1991) should be used, we **recommend** that:

FAUs AND RESEARCH, THROUGH FURTHER INVESTIGATION, IMPROVE THE PRECISION OF THE REFERENCE VALUES FOR EFFORT AND ABUNDANCE

FAUs ESTABLISH A REFERENCE VALUE FOR SPRING INDEX GILLNETTING CUE

Mortality

Lester et al. (1991) proposed a length index (mean length above 400 mm or ML400) as a growth dependent index of mortality. Use of the 400 mm length criterion presumes that fish of this length and greater are fully represented in angler's catches or index nets. The use of ML400 can be used to determine the proportion of lakes which exceed a management guideline, such as a *maximum* annual mortality rate of 45%. We **recommend** that:

THE MORTALITY INDEX, ML400, BE USED AS A STANDARD FOR COMPARING MORTALITY OF LAKE TROUT AMONG DISTRICT LAKES AND BE FURTHER INVESTIGATED BY FAUs

Growth

Lester et al. (1991) also proposed a growth index (age at 400 mm fork length or A400) which describes expected age at a given length, as a low cost method for evaluating growth in district lakes. The criteria proposed for evaluating growth are based on a L_∞-lake area relationship reported by Payne et al. (1990). Given the relationship between age at 400 mm and L_∞ (Lester et al. (1991), A400 would appear to be an unbiased index of L_∞. A400 provides an estimate of

the proportion of a set of lakes in which asymptotic length exceeds the A400 criterion. The A400 estimates calculated for a set of lakes are compared to the graph prepared by Lester et al. (1991) which is used as a reference value to evaluate lake trout growth. They cautioned that A400 should be estimated from a restricted fork length range (300-500 mm) to reduce scale ageing bias. Both the mortality index and growth index can be used when only scale age data are available. We recommend that:

THE GROWTH INDEX, A400, BE USED AS A STANDARD FOR COMPARING THE GROWTH STATUS OF LAKE TROUT AMONG DISTRICT LAKES AND BE FURTHER INVESTIGATED BY FAUs

Condition

Payne et al. (1990) concluded that condition (weight relative to length) is a sensitive indicator of a change in lake trout population density. An advantage of using condition as an indicator of change is that it involves collecting measurements of known precision (weight and length). Further, its utility as a diagnostic tool does not depend on age assessment with its attendant problems. Payne et al. (1990) formulated a weight-length standard for Ontario lake trout in which the a (weight) and b (length) constants are the reference values. Districts would calculate the a and b values to compare against the provincial values shown in the Payne et al. (1990) equation. We recommend that:

FISHERIES MANAGERS IN ONTARIO ADOPT A NEW PROVINCIAL STANDARD WEIGHT-LENGTH REGRESSION TO DETECT DIFFERENCES IN LAKE TROUT POPULATION DENSITY AMONG LAKES AS FOLLOWS: $W = 3.88 \times 10^{-6} L^{3.18}$

where W is the weight in g and L is fork length in mm.

THE LAKE TROUT MANAGEMENT SUPPORT SYSTEM

The Lake Trout Management Support System is an interactive computer-based model, adapted from the model in Evans et al. (1991a), designed to assist managers in evaluating lake trout management options. Parameter estimates are calculated primarily from extensive knowledge about Lake Opeongo lake trout populations. To generalize the model beyond Lake Opeongo,

empirical relationships between lake area and key population parameters have been defined, some of which are presented in Payne et al. (1990). This age-structured population model allows the user to specify a wide range of management options such as stocking or changes in catch or size limits to explore the effects of such actions on both wild and stocked populations, alone or in combination, during a 50 year time horizon. The user can also change input parameters (e.g., growth, mortality rates) to use independently obtained information about a particular lake and to explore the implications of varying assumptions such as the survival and reproductive success of stocked fish. We **recommend** that:

THE LAKE TROUT MANAGEMENT SUPPORT SYSTEM BE USED TO ASSIST MANAGERS IN EVALUATING LAKE TROUT MANAGEMENT OPTIONS

THE ECOSYSTEM HEALTH INDEX

The Ecosystem Health Index (formerly known as the Dichotomous Key) represents an application of the indicator organism concept to the assessment of ecosystem health (Ryder and Edwards 1985; Marshall et al. 1987). Specifically, the lake trout is used to assess the quality of oligotrophic systems, including both the Great Lakes and smaller inland lakes. The index takes the form of a simple, menu-driven computer program, which poses critical questions about lake trout, its aquatic community associates, and its environment. Responses indicate the degree to which the operational niche boundaries for lake trout have departed from those characteristic of a pristine state and denote the occurrence of anthropogenic stressors, as related to exploitation, community alterations, and degradation of lake trout habitat and the aquatic environment in general. The index is designed to educate the user and often exposes or places emphasis on a stressor previously undetected or not thought to be critical. Graphic representations provided by the key assist the manager by identifying the detected stresses, determining data deficiencies, and facilitating inter-lake comparisons and temporal monitoring of ecosystem health. We **recommend** that:

THE ECOSYSTEM HEALTH INDEX BE USED BY MANAGERS AS A DIAGNOSTIC TOOL FOR EVALUATING THE STATUS OF LAKE TROUT COMMUNITIES

Growth is a useful indicator of relative ecosystem health because it responds to changes in density, which in turn can be caused by a variety of stressors. Growth parameters are of interest in examining growth changes over time as well as characterizing the population growth as a whole. Some aspects of growth rate have been used in the development of the Ecosystem Health Index. Payne et al. (1990) proposed a growth relationship (L_∞ = 29.0 + 10.7 $\log_{10}$ Area), which Lester et al. (1991) supported for evaluating district lakes. We **recommend** that:

THE EQUATION $L_\infty = 29.0 + 10.7 \log_{10}$AREA BE USED TO EVALUATE GROWTH CHARACTERISTICS OF LAKE TROUT IN DISTRICT LAKES

where L_∞ is the asymptotic length of fish in cm.

THE EQUATION $L_t = 59.9(1-e^{-0.168t})$ BE USED AS A NEW PROVINCIAL LENGTH-AT-AGE STANDARD FOR LAKE TROUT

where L_t is length-at-age in cm, e is a constant 2.7183, and t is age in years.

THE FISH COMMUNITY TYPE CONCEPT

Carl et al. (1990) found that lake trout angling yield was highly variable among the fish community types. Given the small sample size and correlation among variables, they were unable to show significant differences in abundance and yield. Analyses by Carl et al. (1990) revealed that creel survey data, while important for management, cannot be used to evaluate community effects. However, gillnet data, which removed the effects of angler effort, indicated that in lakes with coregonines and predators such as burbot and northern pike, lake trout relative abundance was lower. They speculated that this might be due to predation and/or competition.

Carl. et al. (1990) concluded that in the absence of better information, the assessment unit lakes should continue to be based on the FCT concept. The inability to adequately evaluate the FCT concept during the lake trout synthesis highlights the need for further research into the factors affecting lake trout productivity and yield. We **recommend** that:

STUDIES DIRECTED AT DETERMINING FACTORS AFFECTING LAKE TROUT PRODUCTIVITY AND YIELD BE DONE IN THE CONTEXT OF THE FISH COMMUNITY TYPE CONCEPT

A THEORY OF LAKE TROUT MANAGEMENT

Lake area has a profound effect on the productivity, growth, and mortality relations of lake trout. Small lakes appear to be inherently more productive than large lakes. Small lake trout lakes are generally characterized as having fewer predators and competitors, smaller prey size, smaller but earlier maturing lake trout, higher lake trout biomass, higher fishing intensity, and higher angling yield per-unit-area than large lakes.

The population dynamics of lake trout are important determinants of lake trout productivity. Payne et al. (1990) noted that the higher von Bertalanffy K values and natural mortality rates characteristic of lake trout in small lakes signify higher turnover rates which determine the potential for yield. However, on small lakes, yield is highly sensitive to changes in the instantaneous rate of fishing mortality (F). Small lakes require a lower rate of F to achieve the MSY. That is, vulnerability to overexploitation increases as the F required to attain MSY decreases. Very small increases in F can cause abrupt changes in the sustained yield curve because its MSY peak is narrower for small lakes (Payne et al. 1990). The decline in yield beyond MSY is much steeper for these small lakes. The net effect is that small lakes are more sensitive to overexploitation and are less able to compensate for overfishing than large lakes. The theoretical relationship between lake area and yield, effort, and mortality is depicted in Fig. 3.

Small lake trout lakes tend to be characterized by populations of small, planktivorous lake trout, which mature earlier and which are recruited to a fishery at a smaller size and younger age. In these stocks, the age at vulnerability to fishing is similar to the age at first maturity, whereas in piscivorous stocks age of first vulnerability precedes first maturity by some years. This is an advantage for planktivorous stocks, because it means faster turnover rates which imply higher sustainable yields. These stocks are numerically more abundant per-unit-area than piscivorous stocks and this suggests that a fairly large proportion of a given year-class escapes the fishery to spawn. Gresswell (1980) noted that harvesting fish prior to maturity "shifts mortality to life stages which may be better able to withstand high levels of exploitation." However, in planktivorous lake trout stocks, the catch is dependent on fewer year-classes and year-class

strength is more variable than with piscivorous stocks (Martin 1966). This supports Payne et al's. (1990) conclusion that there is a risk associated with exploiting these small productive lake trout lakes.

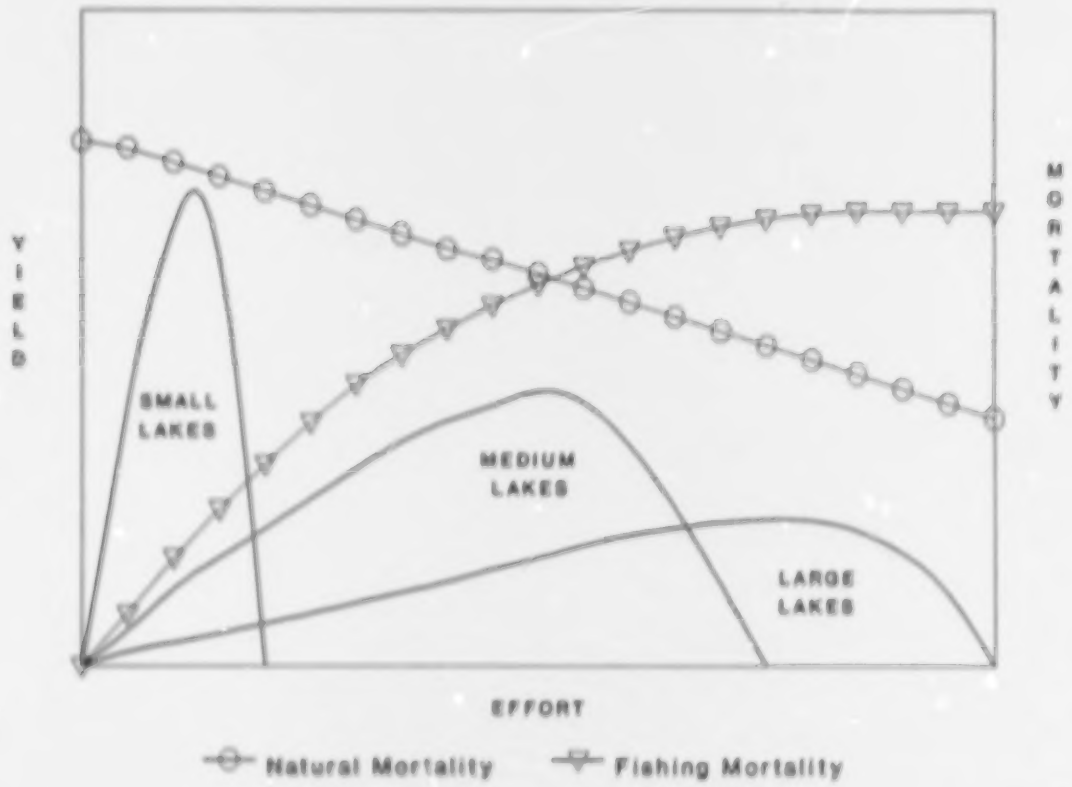

Fig.3. The theoretical relation between effort, yield, mortality, and lake size for lake trout lakes in Ontario.

Feeding efficiency may also affect productivity of lake trout stocks. Lake trout are inefficient planktivores (Langeland et al. in press). Martin and Kerr (1970) argued that, contrary to trophodynamic theory, lake trout are not more productive in small lakes than in large lakes because differences in energy costs and prey size between planktivorous and piscivorous stocks effectively balance each other out. Lake trout appear to be more efficient foragers on intermediate sized prey (large invertebrates, such as *Mysis*) than on the much smaller zooplankton species. Carl et al. (1990) argued that yield could be higher for lake trout stocks

that feed primarily on large invertebrates because they would incur lower energy costs in searching for prey than planktivores and lower trophic level transfer costs than piscivores. The presence or absence of coregonines and large invertebrates may be a key factor in explaining differences in productivity among lake trout lakes.

The number of fish species present in a lake increases with lake size. Both the number and type of species present may affect abundance, growth, and productivity. Carl et al. (1990) noted that after an initial high growth efficiency, lake trout showed a tendency to rapidly declining growth efficiency and small maximum size in lakes where coregonines were not present, while yield tended to be higher in lakes with few predators and competitors. There is also a positive relation between lake area and the mean and maximum size of lake trout, perhaps because lake trout in the larger lakes are primarily piscivorous. Characteristics of lake trout lakes relative to lake size are summarized in Table 2.

Lake area is a single, key surrogate factor for a suite of difficult to measure factors which affect lake trout stocks. We know that parameters such as effort, harvest, yield, productivity, mortality rates, growth rates, diet, feeding efficiency, maximum and average size, age to first maturity, turnover rates, and the number of competitors and predators change with lake area. Thus, a knowledge of lake area tells us much about these parameters and hence, can act as a surrogate for some of those less easily measured. It is also easier to determine management regimes for sets of lakes on the basis of their lake area, than it is say, on the basis of mortality rates or growth rates. The relationships of yield and fishing intensity to lake area strongly support the management of lake trout lakes on this basis.

The paradox of lake trout management is that although small lakes are more productive, they are also more at risk to overharvest, because lower fishing mortality rates are needed to achieve MSY (Payne et al. 1990), and the catch of the planktivorous stocks typically found in these small lakes is dependent on fewer year-classes and year-class strength is more variable (Martin 1966). Thus, a more conservative management regime is necessary on small lakes.

Table 2. The relation of lake area to species, community and fishery attributes of lake trout stocks and lake trout lakes.

Attributes	Lake Area		
Species	Small	Medium	Large
mean size	small	intermediate	large
maximum size	small	intermediate	large
maturity	early	early/medium	late
diet	planktivore	plank/benth	pisc.
feeding/growth efficiency	low	intermediate	high
growth rate	slow	intermediate	fast
energy costs-prey search	high	intermediate	low
trophic level transfer costs	low	intermediate	high
year-class strength	variable		even
spawning escapement	high	high	low
abundance ($area^{-1}$)	high	high/medium	low
biomass ($area^{-1}$)	intermediate	high	low
nat.mort.rate	high	intermediate	low
turnover rate	high	high/medium	low
productivity	intermediate	high	low
risk of overharvest	high	intermediate	low
Community			
total no. species	low	intermediate	high
no. of predators	low	intermediate	high
no. of competitors	low	intermediate	high
prey size	small	intermediate	large
Fishery			
effort	low	intermediate	high
fishing intensity	high	high	low
harvest	low	intermediate	high
yield	high	high	low
year-classes in catch	fewest	few	many
recruitment size	small	small	large
recruitment age	low	low	high
difference between maturity and recruitment ages	small	small	large

RATIONALE

Given the current status of the lake trout in Ontario and its uncertain future, it is important that the rationale for managing lake trout is understood and stated clearly. Although OMNR has the mandate to manage the fisheries resources of the province, there are also compelling social, cultural, economic, and biological reasons for managing lake trout.

The rationale for the management of lake trout by the Ontario Ministry of Natural Resources is:

- Ministry goals, objectives, and strategic directions (see Appendix B) require intensive management of lake trout;
- As the custodian and steward of the province's fisheries resources, the Ministry is responsible for the continued survival and health of fish stocks, including lake trout, to satisfy in part, society's future needs and wants;
- The number of Ontario lakes supporting lake trout (some 2200) is only a small percentage (<1%) of the total number in the province, yet represents about 20-25% of all lake trout lakes in the world;
- Given the number of lake trout lakes in the province and their total area (including Ontario's portion of the Great Lakes), Ontario has the greatest responsibility in the world for the management of this species;
- The lake trout resource is small in relation to demand with many lakes now supporting fisheries for lake trout equal to, or greater than, the resource capability to sustain them;
- The lake trout is a desirable species which provides a high quality recreational experience by virtue of its size, appearance, eating quality, sporting characteristics, and environmental aesthetics;
- The lake trout is the only native piscivore of both sport and commercial importance which is adapted to live in the hypolimnion of lakes. This species contributes significantly to the Ministry's ability to satisfy demands for angling opportunities and wholesome fish;
- A significant number (5%) of previously naturally reproducing lake trout stocks in Ontario are now extinct. Many more are affected by man-induced stresses. Unless carefully managed, many of the remaining stocks together with their socioeconomic benefits will be permanently reduced or lost;

- Rehabilitation of self-reproducing stocks, especially in the Great Lakes, will, if successful, restore these formerly valuable fisheries and reduce or eliminate the need for ongoing and costly stocking programs;

- Exploitation is the most critical stressor affecting lake trout in Ontario. They are caught easily, and under existing angling regulations, lake trout can be legally overharvested and their stocks depleted with only a moderate amount of fishing;

- The inherent biological attributes and highly specialized nature of the species (slow growth, late maturity, low reproductive potential, slow replacement rate) each contribute to the lake trout's vulnerability to exploitation;

- Lake trout inhabit unproductive lakes (cold water, low nutrients) where they form sparse populations which produce low, annual sustainable yields;

- Stringent life history and habitat requirements of lake trout afford little possibility of expanding the resource base for lake trout. Hence, those few lakes with lake trout and their lake stocks must be managed carefully;

- Loss of native self-reproducing stocks means a loss of unique gene pools and a reduction in genetic diversity, thus narrowing the options available to manage lake trout in the future;

- The lake trout, because of its biological characteristics and rigorous life history requirements, is a sensitive environmental indicator of ecosystem health;

- The lake trout, as a keystone predator, integrates community structure and contributes to fish community stability by regulating predator-prey balance;

- The lake trout is an important vector of energy and nutrients between the shallow littoral zone and the deep offshore waters of large lakes;

- The lake trout is a lake-shoal spawner and thus does not compete with other salmonids for spawning and rearing habitat in streams;

- Managing lake trout lakes as a provincial priority is in accord with the province's strategic planning and sustainable development initiatives and the public expectation for greater attention to the environment. Lake trout lakes are a focal point for this emerging direction;

- Lake trout are part of the cultural and social heritage of Ontario;

- Fisheries for lake trout generate more than 100 million dollars in direct benefits to the Ontario economy each year; and

- Lake trout and lake trout lakes are integral to the development of the type lake, community type and index species concepts applied by Ontario fisheries managers.

A goal statement for lake trout is a logical extension of the development of a rationale for managing the species. This statement defines the dimensions of the Ministry's commitment to the management of lake trout. It provides direction to managers and notifies the public about the intent of the Ministry with respect to lake trout. We propose the following:

The **GOAL** of the Ontario Ministry of Natural Resources for lake trout management

> **TO MANAGE THE LANDS AND WATERS (ECOSYSTEMS) OF ONTARIO TO MAINTAIN AND REHABILITATE LAKE TROUT COMMUNITIES, PRIMARILY THROUGH NATURAL REPRODUCTION, TO PROVIDE FOR GENETIC DIVERSITY, EDIBLE FISH, AND HIGHLY-VALUED FISHING OPPORTUNITIES**

PROVINCIAL FISH

We undertook a survey of the provinces and states in North America to see if any jurisdictions had designated or were planning to identify an "official fish". In Canada, none of the provinces or territories have designated a provincial fish, and none planned to proceed with such an initiative at this time. Only two provinces indicated some interest in designating a provincial fish - and in one province, Quebec, the lake trout was mentioned as a possibility, but along with three other species. Canada has not designated a national fish and we do not perceive that this is likely to happen.

Across the United States, official recognition of animals, plants and minerals is commonplace. The designation of a state flower, bird, tree, mineral, gemstone, fish, fossil, and insect occurs in many, if not most, state jurisdictions. Twenty-five states recognize officially a "state fish" and in a few cases, two species are identified. No state has recognized lake trout as "its" fish, although the State of Michigan comes the closest with the designation "trout" as the state fish.

Ontario and other provinces have occasionally noted things of special interest and have taken official steps to have them designated as provincial emblems. In Ontario, the trillium is well known as the provincial flower, and more recently, the common loon was selected to become the provincial bird.

The recognition and occasional designation of unique, commonplace and often beautiful animals, plants and things often occur in jurisdictions which venerate and respect their past. These official emblems have usually figured prominently in a jurisdiction's historical and cultural heritage or are uniquely recognized. Often, these emblems are drawn from the natural world. The motives for undertaking such a process are varied and multi-faceted and include: recognizing special natural features; raising the profile of these items; and helping to create an aura of uniqueness and the need to care for these distinctive features. There are important educational values associated with the practice as well.

Lake trout historically, and into the present, have played an important role in Ontario's commercial and recreational fisheries. In addition to being a native species, the lake trout occurs over much of the province including both inland lakes and the Great Lakes. It is widely recognized. Not only is there prestige associated with lake trout as part of a "desirable catch", but the lake trout is also important as an environmental indicator of healthy lakes. Much of Ontario's fisheries rehabilitation effort is directed towards lake trout. To some there is a romantic allure associated with lake trout, embodied in such descriptive names as great grey trout and namaycush.

Lake trout in Ontario are "special" and as such, deserve unique attention and care. It is our expectation that by raising the profile of the lake trout by designating it as the provincial fish, benefits will accrue to both the species and to the province. We recommend that:

OMNR UNDERTAKE TO HAVE THE LAKE TROUT OFFICIALLY DESIGNATED AS ONTARIO'S PROVINCIAL FISH

CONCLUSIONS

The lake trout is a sensitive species because of: its ecological requirements - the rigorous constraints imposed by the cold and unproductive ecosystems it inhabits; its vulnerability to all forms of human-imposed stressors; and its inability to adapt to and cope with rapidly changing environmental conditions. These conditions assure that it can only exist in a small number of lakes throughout the world. It is susceptible to population collapse and extinction - a situation compounded by the fact that population loss may occur subtly and over a matter of decades. This slow process of attrition tends to defuse any sense of urgency to take strong corrective measures. Irrespective of the cause of extinction, it is not just fisheries that are threatened. Genetic diversity is reduced and unique gene pools may be lost forever.

The lake trout in Ontario faces a precarious and uncertain future. The impact of human activities on lake trout has been so acute that its very existence may be in jeopardy. In their epilogue, Martin and Olver (1980) stated that "The lake charr is extremely sensitive to exogenous man-induced perturbations. It is essential that pristine conditions be maintained for the well-being of this species". The prediction of Ryder and Johnson (1972) that "at the present rate of interference of the oligotrophic environment by man that salmonid communities will be reduced to insignificant levels within the next 30 years" may well come to pass.

The lake trout, more than any other fish species native to Ontario, symbolizes the dilemma posed by a society which professes a desire to preserve species such as the lake trout, yet continues to expose the fish and its habitat to stresses which can cause its ultimate demise.

The message is clear. Strong measures are needed to ensure healthy, self-sustaining populations of lake trout. Only through a conservation-oriented strategy can the people of Ontario continue to derive social and economic benefits from the lake trout resource. Our strategy recognizes the limited nature of the resource, the need for strict controls and the necessity of an ecosystem approach to management. The emphasis should be on public understanding and acceptance of a management regime centred on the provision of high quality environments and low annual yields sustained by natural reproduction.

RECOMMENDATIONS

ADMINISTERING THE FISHERIES

MANAGERS TAKE ADVANTAGE OF PLANNING PROCESSES THAT PROVIDE OPPORTUNITIES FOR LAND USE DESIGNATIONS WHICH PROTECT LAKE TROUT LAKES (p.9)

THE PROVINCE'S SPECIAL CONCERNS ABOUT ONTARIO LAKE TROUT LAKES BE ADDRESSED BY MUNICIPALITIES IN OFFICIAL PLANS (p.9)

FISHERIES POLICY BRANCH INTENSIFY ITS EFFORTS TO PROVIDE CLEAR DIRECTION, GUIDELINES, AND POLICY FOR THE EFFICIENT APPLICATION OF THE FEDERAL FISHERIES ACT AS THE PRIMARY LEGISLATION FOR MANAGING FISH HABITAT IN ONTARIO (p.10)

OMNR CONTINUE TO SEEK RESTITUTION FOR, AND RESTORATION OF, DEGRADED HABITAT THROUGH THE FISHERIES ACT, THE PUBLIC LANDS ACT, AND THE LAKES AND RIVERS IMPROVEMENT ACT (p.10)

OMNR DEVELOP INITIATIVES TO MAKE MUNICIPALITIES AND DEVELOPERS AWARE OF THE MINISTRY'S PRIORITY INTEREST IN LAKE TROUT LAKES AND THE SENSITIVITY OF LAKE TROUT LAKES TO DEVELOPMENT (p.10)

OMNR DEVELOP AND COORDINATE A PROGRAM TO MAKE DEVELOPERS AWARE OF APPROVAL PROCEDURES AND THEIR LEGAL OBLIGATIONS (p.10)

OMNR PLANNING DOCUMENTS EXPLICITLY IDENTIFY LAKE TROUT LAKES AS A RESOURCE OF PROVINCIAL PRIORITY, WARRANTING FULL PROTECTION FROM ADVERSE ENVIRONMENTAL IMPACTS (p.11)

THE DISTRICT FISHERIES MANAGEMENT PLANNING PROCESS BE REVIEWED AND MECHANISMS BE DESIGNED TO IMPROVE THE DEVELOPMENT AND COORDINATION OF MANAGEMENT INITIATIVES, INCLUDING THOSE FOR LAKE TROUT (p.11)

THE POLICY PROCESS BE FULLY UTILIZED AS A MEANS TO PROTECT LAKE TROUT LAKES IN ONTARIO, INCLUDING THE EXPLORATION OF A FORMAL POLICY STATEMENT UNDER THE PLANNING ACT (p.12)

FISHERIES MANAGEMENT TARGETS EMPHASIZE CONSERVATION OBJECTIVES (p.12)

OMNR IMPROVE THE UNDERSTANDING OF ITS CLIENTS ABOUT THE OBJECTIVES AND PRINCIPLES OF SUSTAINABLE RESOURCE MANAGEMENT (p.13)

OMNR PLACE MAJOR EMPHASIS ON ALLOCATION STRATEGIES WHICH ENSURE LONG-TERM MAINTENANCE OF THE RESOURCE (p.13)

EXPLOITATION

THE THV FORMULA BE USED TO CALCULATE THE MAXIMUM POTENTIAL HARVEST OF LAKE TROUT IN ONTARIO LAKES (p.19)

THE EQUATION $\log_{10}Y = 0.60 + 0.72\log_{10}A$ BE USED TO CALCULATE THE POTENTIAL HARVEST OF LAKE TROUT FROM LAKE AREA (p.20)

THE DIAGNOSTIC TOOLS PRESENTED IN FIGS. 1-6 AND 9-13 (EVANS ET AL. 1991a) BE USED AS FIRST ORDER INDICATORS OF THE RELATIVE EXPLOITATION STATUS OF LAKE TROUT POPULATIONS ON LAKES WHERE HARVEST DATA ARE AVAILABLE (p.22)

ADDITIONAL DATA BE ACQUIRED TO BROADEN THE SCOPE OF THE LESTER ET AL. (1991) FISHERIES DEVELOPMENT MODEL (p.23)

OMNR CONDUCT FURTHER STUDIES ABOUT THE RELATION BETWEEN LAKE SIZE AND SUSTAINABLE YIELD (p.23)

LAKE TROUT LAKES 100 HA AND LESS BE CLOSED TO WINTER FISHING (p.24)

THE WINTER LAKE TROUT SEASON BE REDUCED ON ALL LAKE TROUT LAKES < 1000 HA TO ONE MONTH (FEBRUARY 15 - MARCH 15) (p.25)

FOR THE MAINTENANCE OF SELF-SUSTAINING LAKE TROUT STOCKS AND THE REHABILITATION OF PLANTED STOCKS, A TOTAL ANNUAL MORTALITY OF 45% BE USED TO IDENTIFY OVERHARVEST AND AS A CRITERION FOR ESTABLISHING REGULATIONS TO CONTROL OVERHARVEST (p.26)

ADDITIONAL STUDIES OF LAKE TROUT WINTER HOOKING MORTALITY BE CONDUCTED WITH PARTICULAR REFERENCE TO SIZE-SPECIFIC CONSIDERATIONS (p.28)

FISHERIES MANAGERS USE THE $F_{0.1}$ MODEL TO DETERMINE THE LENGTH-AT-AGE FOR SETTING MINIMUM SIZE LIMITS (p.29)

THE UTILITY OF SIZE LIMITS FOR LAKE TROUT CONTINUE TO BE INVESTIGATED (p.30)

ANY REGULATIONS PERTAINING TO THE USE OF GEAR BE TESTED EXPERIMENTALLY BEFORE WIDE APPLICATION (p.30)

THE USE AND IMPACT OF "HI-TECH" GEAR ON LAKE TROUT STOCKS AND FISHERIES BE EVALUATED AS A ROUTINE PART OF CREEL SURVEYS AND THROUGH EXPERIMENTATION (p.30)

ONLY ONE LINE PER ANGLER BE ALLOWED DURING WINTER FISHING ON LAKE TROUT LAKES (p.31)

THE FEASIBILITY OF IMPLEMENTING A TAG AND QUOTA SYSTEM TO REDUCE LAKE TROUT EXPLOITATION BE INVESTIGATED (p.32)

OMNR EXPLORE THE POSSIBILITY OF ESTABLISHING, ON AN EXPERIMENTAL BASIS, A MANAGEMENT MODEL BASED ON THE ZEC CONCEPT (p.34)

HABITAT

THE USEABLE HABITAT VOLUME FOR LAKE TROUT, WITH PARTICULAR EMPHASIS ON DEEP-WATER NURSERY HABITAT, BE RECOGNIZED AS A SENSITIVE INDICATOR OF HABITAT SUITABILITY FOR LAKE TROUT AND BE FULLY CONSIDERED BY MANAGERS IN THE PROTECTION OF LAKE TROUT HABITAT (p.38)

RESEARCH ON LAKE TROUT HABITAT DESCRIPTORS SHOULD FOCUS ON DEFINING MORE PRECISE DIMENSIONS OF JUVENILE HABITAT AND ON RELATING THIS TO USEABLE HABITAT VOLUME (p.39)

THE FOLLOWING DIAGNOSTIC KEYS BE USED TO ASSESS THE REPRODUCTIVE STATUS OF LAKE TROUT STOCKS AS THEY REPRESENT THRESHOLDS FOR EXTINCTION: (p.39)

OPTIMUM HABITAT VOLUME IS $<20\%$ OF TOTAL LAKE VOLUME AND USEABLE HABITAT VOLUME IS $<40\%$ OF TOTAL LAKE VOLUME

$\geq 6\%$ OF TOTAL LAKE VOLUME HAS A DISSOLVED OXYGEN CONCENTRATION FROM 2-4 mg L^{-1}

$\geq 19\%$ OF TOTAL LAKE VOLUME HAS <2 mg L^{-1} OXYGEN

THROUGH POLICY, OMNR EXPLICITLY RECOGNIZE THE INTRINSIC VALUE OF UNDEVELOPED LAKE TROUT LAKES AS AN INTEGRAL COMPONENT OF ONTARIO'S NATURAL HERITAGE AND AS PART OF ONTARIO'S WILDERNESS EXPERIENCE (p.41)

OMNR DISTRICTS IDENTIFY THOSE LAKES WHICH ARE TO BE MANAGED FOR LAKE TROUT, CLEARLY IDENTIFYING THOSE ON WHICH NO FURTHER DEVELOPMENT WILL BE PERMITTED, AND THOSE ON WHICH PRIVATE DEVELOPMENT WILL BE PERMITTED WITH SPECIFIED CONDITIONS (p.41)

CROWN LAND ON LAKE TROUT LAKES NOT BE DEVELOPED OR PATENTED FOR SEASONAL OR PERMANENT DWELLINGS WITHIN 400 m OF THE SHORELINE (p.41)

OPTIMUM HABITAT MODELS BE REVIEWED BY THE MINISTRIES OF THE ENVIRONMENT AND NATURAL RESOURCES AND A COORDINATED APPROACH BE ADOPTED AS PROVINCIAL POLICY FOR MANAGING DEVELOPMENT ON LAKE TROUT LAKES (p.44)

AGREEMENTS FOR WATER DRAWDOWNS ON LAKE TROUT LAKES BE NEGOTIATED TO MITIGATE THE IMPACT ON SPAWNING SHOALS (p.44)

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STOCK SELECTION GUIDELINES BE DEVELOPED TO REVIEW THE GENOTYPIC AND PHENOTYPIC CHARACTERISTICS OF STOCKS UNDERGOING REHABILITATION (p.49)

THE DONOR STOCKS REQUIRED TO MEET MANAGEMENT NEEDS ACROSS THE PROVINCE BE CLEARLY DETERMINED (p.49)

SUPPLEMENTAL STOCKING OF LAKE TROUT NOT BE PERMITTED (p.49)

REHABILITATION STOCKING NOT BE PERMITTED IN LAKES WHERE NATIVE LAKE TROUT STILL EXIST, UNLESS NATIVE STOCKS ARE USED (p.49)

STOCKING BE PERMITTED TO REHABILITATE LAKES IN WHICH THE NATIVE STOCK HAS BECOME EXTINCT, OR TO EXTEND THE RANGE OF LAKE TROUT (p.49)

STOCKING BE PERMITTED IN THE FEW LAKES IN ONTARIO WHICH CAN BE LEGITIMATELY CLASSIFIED AS PUT-GROW-TAKE. ALL OF THESE LAKES SHOULD BE ASSESSED TO ENSURE THAT NATIVE STOCKS DO NOT EXIST (p.50)

INLAND LAKES WHICH REQUIRE REHABILITATIVE STOCKING BE CLOSED TO EXPLOITATION FOR LAKE TROUT UNTIL THE PROCESS IS COMPLETE (p.50)

ALTERNATIVELY, A VERY RESTRICTIVE FORM OF CATCH-AND-RELEASE FISHING (NO KILL OF FISH) BE CONSIDERED (p.50)

EXPLOITATION ON THE GREAT LAKES AND LARGE INLAND LAKES BE CONTROLLED AT A RATE WHICH IS CONDUCIVE TO REHABILITATION (A <0.45) (p.50)

OMNR CONTINUE TO PROMOTE CATCH-AND-RELEASE FISHING FOR LAKE TROUT (p.51)

NEW SPECIES NOT BE STOCKED INTO LAKE TROUT LAKES (p.54)

THE USE AND POSSESSION OF LIVE BAITFISH IN LAKE TROUT LAKES BE PROHIBITED (p.54)

THE PRESENCE OR ABSENCE OF LARGE INVERTEBRATES BE DETERMINED AS A STANDARD PRACTICE IN ONTARIO LAKE SURVEYS (p.56)

PREDATOR-PREY DYNAMICS BE INCLUDED IN RESEARCH ABOUT FACTORS AFFECTING LAKE TROUT PRODUCTIVITY AND SUSTAINABLE YIELD (p.56)

ASSESSING THE STATUS OF LAKE TROUT STOCKS

OMNR ADOPT THE LESTER ET AL. (1991) SAMPLING FRAMEWORK THAT EMPHASIZES THE LINKAGES BETWEEN INTENSIVE MONITORING OF FAU LAKES AND EXTENSIVE MONITORING OF DISTRICT LAKES (p.60)

A STANDARD ASSESSMENT PROGRAM FOR FAU LAKES BE ESTABLISHED THAT WILL PERMIT THE DEVELOPMENT AND TESTING OF LAKE TROUT POPULATION MODELS AND THE PERIODIC RE-EVALUATION OF PROVINCIAL REFERENCE VALUES FOR LAKE TROUT (p.60)

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THE PRIORITY FOR MONITORING DISTRICT LAKES BE BASED ON THE HIERARCHY OF RESOURCE INVENTORY, EFFORT INDEXING, AND CATCH INDEXING (p.60)

A STANDARD DISTRICT LAKE MONITORING PROGRAM BE ESTABLISHED THAT USES

INDIRECT RAPID ASSESSMENT TECHNIQUES TO DETERMINE INDICES WHICH ALLOW THE COMPARISON OF THEIR LAKE TROUT POPULATIONS AGAINST PROVINCIAL REFERENCE VALUES (p.60)

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DISTRICTS ADOPT THE EFFORT INDEX, MAC, AS A LOW COST METHOD FOR EVALUATING ANNUAL EFFECTIVE EFFORT (p.61)

FAUs CONFIRM THE USE OF MAC AS THE MOST APPROPRIATE ESTIMATOR OF ANNUAL EFFECTIVE EFFORT (p.61)

FAUs AND RESEARCH, THROUGH FURTHER INVESTIGATION, IMPROVE THE PRECISION OF THE REFERENCE VALUES FOR EFFORT AND ABUNDANCE (p.62)

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THE MORTALITY INDEX, ML400, BE USED AS A STANDARD FOR COMPARING MORTALITY OF LAKE TROUT AMONG DISTRICT LAKES AND BE FURTHER INVESTIGATED BY FAUs (p.62)

THE GROWTH INDEX, A400, BE USED AS A STANDARD FOR COMPARING THE GROWTH STATUS OF LAKE TROUT AMONG DISTRICT LAKES AND BE FURTHER INVESTIGATED BY FAUs (p.63)

FISHERIES MANAGERS IN ONTARIO ADOPT A NEW PROVINCIAL STANDARD WEIGHT-LENGTH REGRESSION TO DETECT DIFFERENCES IN LAKE TROUT POPULATION DENSITY AMONG LAKES AS FOLLOWS: $W = 3.88 \times 10^{-6} L^{3.42}$ (p.63)

THE LAKE TROUT MANAGEMENT SUPPORT SYSTEM BE USED TO ASSIST MANAGERS IN EVALUATING LAKE TROUT MANAGEMENT OPTIONS (p.64)

THE ECOSYSTEM HEALTH INDEX BE USED BY MANAGERS FOR EVALUATING THE STATUS OF LAKE TROUT COMMUNITIES (p.64)

THE EQUATION $L_\infty = 29.0 + 10.7 \log_{10}$AREA BE USED TO EVALUATE GROWTH CHARACTERISTICS OF LAKE TROUT IN DISTRICT LAKES (p.65)

THE EQUATION $L_t = 59.9(1-e^{-0.10t})$ BE USED AS A NEW PROVINCIAL LENGTH-AT-AGE STANDARD FOR LAKE TROUT (p.65)

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PROVINCIAL FISH

OMNR UNDERTAKE TO HAVE THE LAKE TROUT OFFICIALLY DESIGNATED AS ONTARIO'S PROVINCIAL FISH (p.74)

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REFERENCES

ABBEY, E. 1968. One Life at a Time, Please. Henry Holt and Company, New York, NY. 225p.

BARBOUR, C. D., and J. H. BROWN. 1974. Fish species diversity in lakes. Am Nat. 103:473-489.

BEAMISH, R. J. 1976. Acidification of lakes in Canada by acid precipitation and the resulting effects on fishes. Water, Air, Soil Pollut. 6:501-514.

BEAMISH, R. J., and H. H. HARVEY. 1972. Acidification of the La Cloche Mountain lakes, Ontario and resulting fish mortalities. J. Fish. Res. Board Can. 29:1131-1143.

BEDI, N., D. FARQUHAR, and D. LEGG. 1990. 1985 surveys of Ontario's resident and non-resident sport fishermen: selected results from 1980 through 1985 angler surveys. Ont. Min. Nat. Resour., Fish. Br.

BEGGS, G. L., J. M. GUNN, and C. H. OLVER. 1985. The sensitivity of Ontario lake trout (*Salvelinus namaycush*) and lake trout lakes to acidification. Ont. Fish. Tech. Rep. Ser. No. 17. 24p.

BEHNKE, R. J. 1972. The systematics of salmonid fishes of recently glaciated lakes. J. Fish. Res. Bd. Canada 29: 639-671.

BOULANGER, F., and J. CHARBONNEAU. 1989. The report of the evaluation of the G.L.F.C. by the bi-national team, vol. 2. - The analysis of the economic contribution of the Great Lakes sea lamprey control program.

CAMERON, S. 1983. Prospective economic implications of alternative management strategies for lake trout produced by the Iron River National Fish Hatchery. U. S. Fish. Wildl. Serv., Div. Hatcheries and Fish. Resour. Manage. Wash. D. C. Mo Rep. 8 p.

CARL, L., M.-F. BERNIER, W. CHRISTIE, L. DEACON, P. HULSMAN, D. LOFTUS, D. MARALDO, T.MARSHALL, and P. RYAN. 1990. Fish community and environmental effects on lake trout. Lake Trout Synthesis, Ont. Min. Nat. Resour., Toronto. 47 p.

CHAMPLAIN, S. de. 1619. The works of Samuel de Champlain. In six vol. Translated by the Champlain Society, Toronto. 1929. Vol.III (1615-1618), p.45. Translated and edited by H. H. Langton and W. F. Ganong.

CHRISTIE, G. C., and H. A. REGIER. 1988. Measures of optimal thermal habitat and their relationship to yields for four commercial fish species. Can. J. Fish. Aquat. Sci. 45:301-314.

CHRISTIE, W. J. 1972. Lake Ontario: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Bd. Canada 29:913-929.

CHRISTIE, W. J. 1974. Changes in the fish species composition of the Great Lakes. J. Fish. Res. Board Can. 31:827-854.

CHRISTIE, W. J. 1978. A study of freshwater fishery regulation based on North American experience. FAO Fish. Tech. Paper No.180. 46 p.

DEXTRASE, A. J., and H. E. BALL. (in prep.). Hooking mortality of lake trout angled through the ice.

DEPARTMENT OF FISHERIES AND OCEANS. 1988. Sport fishing in Canada 1985. Surveys Unit, Econ. Comm. Analysis Direct. Ottawa.

EMERY, A. R. 1971. Smallmouth bass unit. *In* Research Review, Ann. Rep. Res. Br., Ont. Dep. Lands Forests 1970:49-55.

ESCHMEYER, P. H. 1964. The lake trout (*Salvelinus namaycush*). U. S. Dep. Int. Fish Wildl. Serv. Fish. Leafl. 555. 8 p.

ESHENRODER, R. 1989. A perspective on artificial fishery systems for the Great Lakes. Paper presented at Wild Trout IV, Yellowstone National Park, Sept. 18-19, 1989. 8 p.

EVANS, D. O., B. A. HENDERSON, N. J. BAX, T. R. MARSHALL, R. T. OGLESBY, and W. J. CHRISTIE. 1987. Concepts and methods of community ecology applied to freshwater fisheries management. Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 448-470.

EVANS, D. O., and D. H. LOFTUS. 1987. Colonization of inland lakes in the Great Lakes region by rainbow smelt, *Osmerus mordax*: their freshwater niche and effects on indigenous fishes. Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 249-266.

EVANS, D. O., and P. WAPING. 1987. Changes in the multispecies, winter angling fishery of Lake Simcoe, Ontario, 1961-83: invasion by rainbow smelt, *Osmerus mordax*, and the roles of intra- and interspecific interactions. Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 182-197.

EVANS, D. O., J. M. CASSELMAN, and C. C. WILLOX. 1991a. Effects of exploitation, loss of nursery habitat and stocking on the dynamics and productivity of lake trout populations in Ontario lakes. Lake Trout Synthesis, Ont. Min. Nat. Resour., Toronto. (in prep.)

EVANS, D. O., J. BRISBANE, J. M. CASSELMAN, K. E. COLEMAN, C. A. LEWIS, P.G. SLY, D. L. WALES, and C. C. WILLOX. 1991b. Anthropogenic stressors and diagnosis of their effects on lake trout populations in Ontario lakes. Lake Trout Synthesis, Ont. Min. Nat. Resour., Toronto. 115 p.

GODDARD, C. I., D. H. LOFTUS, J. A. MACLEAN, C. H. OLVER, and B. J. SHUTER. 1987. Evaluation of the effects of fish community structure on observed yields of lake trout (*Salvelinus namaycush*). Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 239-248.

GRESSWELL, R. E. 1980. The effects of the 330 mm maximum size limit on the cutthroat trout fishery of Yellowstone Lake: The first five years, p. 70-76. *In* R. Whaley (ed.). Proceed. 15th annu. meeting Colorado-Wyoming chapter Am. Fish. Soc. 110 p.

GULLAND, J. A., and L. K. BOEREMA. 1975. Scientific advice on catch levels. Fish. Bull. 71 (2): 325-335.

GUNN, J. M., M. J. McMURTRY, J. N. BOWLBY, J. M. CASSELMAN, and V. A. LIIMATAINEN. 1987. Survival and growth of stocked lake trout in relation to body size, stocking season, lake acidity, and biomass of competitors. Trans. Am. Fish. Soc., 116: 618-627.

HARVEY, H. H., and C. LEE. 1982. Historical fisheries changes related to surface water pH changes in Canada, p. 45-55. *In* R. E. Johnson (ed.) Acid rain/fisheries. Proceedings internat. symp. acidic precipitation and fishery impacts in northeastern North America. N.E. Div. Am. Fish. Soc. Bethesda, MD. 357 p.

HASKELL, D. C., R. G. ZILLIOX, and W. M. LAWRENCE. 1952. Survival and growth of stocked lake trout yearlings from Seneca and Raquette Lake broodors. Prog. Fish-Cult. 14:71-73.

HASSINGER, R. L., and T. L. CLOSE. 1984. Interactions of lake trout and rainbow smelt in two northeastern Minnesota lakes. Minn. Dep. Nat. Resour. Sect. Fish. Invest. Rep. 379. 38 p.

HITCHINS, J. R., and W. G. A. SAMIS. 1986. Successful reproduction by introduced lake trout in 10 northeastern Ontario lakes. N. Am. J. Fish. Manage. 6: 372-375.

HISSEN, P. E. 1984. Genetics, p. 15-21. *In* R. L. Eshenroder, T. P. Poe, and C. H. Olver (eds.). Strategies for rehabilitation of lake trout in the Great Lakes: proceedings con. lake trout res., August 1983. Great Lake Fish. Comm. Tech. Rep. 40, 63 p.

JOHNSON, M. G., J. H. LEACH, C. K. MINNS, and C. H. OLVER. 1977. Limnological characteristics of Ontario lakes in relation to associations of walleye (*Stizostedion vitreum vitreum*), northern pike (*Esox lucius*), lake trout (*Salvelinus namaycush*), and smallmouth bass (*Micropterus dolomieui*). J. Fish. Res. Board. Can. 34: 1592-1601.

KERR, S. R., and N. V. MARTIN. 1970. Trophic-dynamics of lake trout production systems, p. 365-376. *In* J. H. Steele (ed.). Marine food chains, Oliver and Boyd, Edinburgh.

LANGELAND, A., L. M. CARL, F. J. HICKS, and B. MONROE. In press. The impact of predation by *Mysis relicta* and fish on zooplankton in four oligotrophic, north temperate lakes. *Mysis* Symposia. Am Fish. Soc. Symp. 00: 000-000.

LASENBY, D. C., T. G. NORTHCOTE, and M. FURST. 1986. Theory, practice and effects of *Mysis relicta* introductions to North American and Scandinavian lakes. Can. J. Fish. Aquat. Sci. 43:1277-1284.

LAWRIE, A. H. 1970. The sea lamprey in the Great Lakes. Trans. Am. Fish. Soc. 99: 766-775.

LAWRIE, A. H., and J. F. RAHRER. 1972. Lake Superior: effects of exploitation and introductions on the salmonid community. J. Fish. Res. Bd. Canada 29: 765-776.

LESTER, N. P., M. M. PETZOLD, W. I. DUNLOP, B. MONROE, S. ORSATTI, T. SCHANER, and D. WOOD. 1991. Sampling Ontario lake trout stocks: issues and standards. Lake Trout Synthesis, Ont. Min. Nat. Resour., Toronto. 117 p.

LEWIS, C. A., G. L. CUNNINGHAM, and T. CHEN. 1990. Analysis of questionnaire on stresses acting on lake trout lakes. Lake Trout Synthesis, Ont. Min. Nat. Resour., Toronto. 77 p.

LI, H. W., and P. B. MOYLE. 1981. Ecological analysis of species introductions into aquatic systems. Trans. Am. Fish. Soc. 110:772-782.

LOFTUS, A. J., W. W. TAYLOR, and M. KELLER. 1988. An evaluation of lake trout (*Salvelinus namaycush*) hooking mortality in the upper Great Lakes. Can. J. Fish. Aquat. Sci. 45: 1473-1479.

LOFTUS, K. H. 1976. A new approach to fisheries management and F. E. J. Fry's role in its development. J. Fish. Res. Board Can. 33: 321-325.

LOFTUS, K. H., M. G. JOHNSON, and H. A. REGIER. 1978. Federal-Provincial strategic planning for Ontario fisheries: management strategy for the 1980s. J. Fish. Res. Board. Can. 35: 916-927.

MacCRIMMON, H. R., C. D. WREN, and B. L. GOTTS. 1983. Mercury uptake by lake trout, *Salvelinus namaycush*, relative to age, growth, and diet in Tadenac Lake with comparative data from other Precambrian Shield lakes. Can. J. Fish. Aquat. Sci. 40:114-120.

MacKAY, H. H. 1956. The lake trout. Ont. Dep. Lands Forests, Sylva 12: 25-28.

MacLEAN, J. A., D. O. EVANS, N. V. MARTIN, and R. L. DESJARDINE. 1981. Survival, growth, spawning distribution, and movements of introduced and native lake trout (*Salvelinus namaycush*) in two inland lakes. Can. J. Fish. Aquat. Sci. 38: 1685-1700.

MacLEAN, N. G., J. M. GUNN, F. J. HICKS, P. E. IHSSEN, M. MALHIOT, T. E. MOSINDY, and W. WILSON. 1990. Genetic and environmental factors effecting the physiology and ecology of lake trout. Lake Trout Synthesis, Ont. Min. Nat. Resour., Toronto. 84 p.

MAGNUSON, J. J. 1976. Managing with exotics - a game of chance. Trans. Am. Fish. Soc. 105: 1-9.

MARSHALL, T. R., R. A. RYDER, C. J. EDWARDS, and G. R. SPANGLER. 1987. Using the lake trout as an indicator of ecosystem health - application of the dichotomous key. Great Lakes Fish. Comm. Tech. Rep. No. 49. 35 p.

MARTIN, N. V. 1966. The significance of food habits in the biology, exploitation, and management of Algonquin Park, Ontario, lake trout. Trans. Am. Fish. Soc. 95: 415-422.

MARTIN, N. V. 1970. Long-term effects of diet on the biology of the lake trout and the fishery in Lake Opeongo, Ontario. J. Fish. Res. Board Can. 27: 125-146.

MARTIN, N. V., and F. E. J. FRY. 1973. Lake Opeongo: the ecology of the fish community and of man's effects on it. Great Lakes Fish. Comm. Tech. Rep. No. 24. 34 p.

MARTIN, N. V., and C. H. OLVER. 1976. The distribution and characteristics of Ontario lake trout lakes. Ont. Min. Nat. Resour. Fish and Wildl. Br. Res. Rep. 97. 50 p.

MARTIN, N. V., and C. H. OLVER. 1980. The lake charr, (*Salvelinus namaycush*), p. 205-277. *In* E. K. Balon (ed.), Charrs, salmonid fishes of the genus *Salvelinus*. Dr. W. Junk BV publishers; The Hague, The Netherlands. 928 p.

MATUSZEK, J. E., B. J. SHUTER, and J. M. CASSELMAN. 1990. Changes in lake trout growth and abundance after introduction of cisco into Lake Opeongo, Ontario. Trans. Am. Fish. Soc. 119: 718-729.

MONGILLO, P. E. 1984. A summary of salmonid hooking mortality. WA Dep. Game Fish Man. Div. Ms Rep. 46 p.

OLVER, C. H. 1988. The regulation of harvest in lake trout sport fisheries: a review and appraisal. Ont. Min. Nat. Resour. Fish. Br., Toronto. Ms Rep. 67 p.

OLVER, C. H., and C. A. LEWIS. 1977. Reproduction of planted lake trout, *Salvelinus namaycush*, in Gamitagoma, a small Precambrian lake in Ontario. *J.* Fish. Res. Board Can. 34: 1419-1422.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1978a. An allocation policy for Ontario fisheries. Report of SPOF Working Group Number Five. 39 p.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1978b. Designation of assessment units. Report of SPOF Working Group Number One. 66p.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1982a. Northeastern Ontario Strategic land use plan. 62 p.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1982b. Southern Ontario coordinated program strategy. 44 p.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1982c. Northwestern Ontario strategic land use plan. 71 p.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1989. MNR strategic directions 1989. Toronto. Mn Rep. 18 p.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1990. A revised strategic plan for Ontario fisheries. An aquatic ecosystem approach. Mn Rep. 12 p. June 1990.

ONTARIO MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT CANADA. 1976. First report. Federal-Provincial strategic planning for Ontario fisheries. Preliminary analysis of goals and issues. 91 p.

ONTARIO MINISTRY OF THE ENVIRONMENT AND THE ONTARIO MINISTRY OF NATURAL RESOURCES. 1977. Report on water quality management of the lake trout waters of southeastern Ontario. 35 p.

ONTARIO MINISTRY OF THE ENVIRONMENT AND THE ONTARIO MINISTRY OF NATURAL RESOURCES. 1980. Report on water quality management of the lake trout waters of southeastern Ontario. Vol. II. 33 p.

PAYNE, N. R., R. M. KORVER, D. S. MacLENNAN, S. J. NEPSZY, B. J. SHUTER, T. J. STEWART, and E. R. THOMAS. 1990. The harvest potential and dynamics of lake trout populations in Ontario. Lake Trout Synthesis, Ont. Min. Nat. Resour., Toronto. 72 p.

PEARSE, P. H. 1988. Rising to the challenge. Can. Wildl. Fed., Ottawa. 180 p.

PLOSILA, D. S. 1977. Relationship of strain and size at stocking to survival of lake trout in Adirondack lakes. N. Y. Fish Game *J.* 24: 1-24.

POWELL, M. J., M.-F. BERNIER, S. J. KERR, G. LEERING, M. MILLER, W. SAMIS, and M. PELLIGRINI. 1986. Returns of hatchery-reared lake trout from eight lakes in northeastern Ontario. Ont. Fish. Tech. Rep. Ser. No. 22. 7 p.

PURYCH, P. B. 1977. Poor returns of hatchery-reared lake trout to the sport fishery of Flack Lake, Ontario, 1968-74. Prog. Fish-Cult. 39: 185-186.

REGIER, H. A., and K. H. LOFTUS. 1972. Effects of fisheries exploitation on salmonid communities in oligotrophic lakes. *J.* Fish. Res. Board Can. 29: 959-968.

RYDER, R. A., 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 93:214-218.

RYDER, R. A. 1972. The limnology and fishes of oligotrophic glacial lakes in North America (about 1800 A.D.). J. Fish. Res. Bd. Canada. 29: 617-628.

RYDER, R. A., and C. J. EDWARDS (eds.). 1985. A conceptual approach for the application of biological indicators of ecosystem quality in the Great Lakes Basin. Report to the Great Lakes Sci. Advisory Board, Internat. Joint Comm. 169 p.

RYDER, R. A., and L. JOHNSON. 1972. The future of salmonid communities in North American oligotrophic lakes. J. Fish. Res. Board Can. 29: 941-949.

RYDER, R. A., and S. R. KERR. 1984. Reducing the risk of fish introductions: a rational approach to the management of integrated coldwater communities, p. 510-533. In Introductions and transplantations. Documents presented at the symposium on stock enhancement in the management of freshwater fisheries. EIFAC Tech. Paper 42. Suppl. Vol. 2. FAO. Rome.

SCARNECCHIA, D. L. 1988. Salmon management and the search for values. Can. J. Fish. Aquat. Sci. 45: 2042-2050.

SMITH, P. A., J. ATKINSON, P. BEWICK, J. JOHNSON, J. MacLEAN, C. OLVER, M. POWELL, P. WARING, B. BROWN, and L. MALES. 1968. A regulatory strategy for Ontario lake trout stocks. Ont. Min. Nat. Resour. Mx Rep.

SMITH, S. H. 1968. Species succession and fishery exploitation in the Great Lakes. J. Fish. Res. Board Can. 25: 667-693.

SMITH, S. H. 1972. Factors of ecologic succession in oligotrophic fish communities of the Laurentian Great Lakes. J. Fish. Res. Board Can. 29: 717-730.

SPANGLER, G. R., A. H. BERST, and J. F. KOONCE. 1981. Perspectives and policy recommendations on the relevance of the stock concept to fishery management. Can J. Fish. Aquat. Sci. 38: 1908-1914.

THOMPSON, P. C. 1974. Institutional constraints in fisheries management. J. Fish. Res. Board Can. 31: 1963-1981.

WYDOSKI, R. S. 1977. Relation of hooking mortality and sublethal hooking stress to quality fisheries management, p. 43-87. In R. A. Barnhart and T. D. Roelofs (ed.) Catch and release fishing as a management tool, a national sport fishing symposium. Humboldt State Univ. Arcata, CA. 221 p.

Appendix A. Terms of reference - Management Strategies Working Group.

Summarize the goal(s), objectives, principles, assumptions and application of present lake trout management practices in Ontario

Summarize the current status of lake trout communities in Ontario

Review and summarize existing and developing issues which influence lake trout communities and their management

Integrate new knowledge arising from the lake trout community synthesis working groups

Review present lake trout management strategies and identify and evaluate new management strategies and tactics

Assess implementation implications for more effective management; discuss goals, policies, guidelines, programs and priorities

Create a product useful to managers

Appendix B. Goals and objectives of the Ontario Ministry of Natural Resources for fisheries management.

Southern Ontario Coordinated Program Strategy (OMNR 1982b)

Ministry Goal

- To provide opportunities for outdoor recreation and resource development for the continuous social and economic benefit of the people of Ontario and to administer, protect and conserve public lands and waters

Outdoor Recreation Objective

- To provide from public lands and water and to encourage on other lands and waters:

  - a wide variety of outdoor recreational opportunities accessible to, and for the continuous benefit of, the people of Ontario;

  - the identification and conservation of unique or representative physical, biological, cultural and historic features of the province; and

  - a continuous contribution to the economy of Ontario from tourism and its related industries

Resource Production Objective

- To provide for an optimum continuous contribution to the economy of Ontario by stimulating and regulating the utilization of available supplies of fish, furbearers, minerals and trees by resource products industries

Fisheries Management Objective

- The objective for fisheries management in southern Ontario is to provide opportunities for recreation and economic benefits consistent with the maintenance of healthy fish communities

Sport Fishing Objective

- To meet demand with the limits of a wisely managed and rehabilitated resource

Commercial Fishing Objective

- To maintain a viable industry

Rare and Endangered Species Objective

- To prevent the extinction of any native species

Northeastern Ontario Strategic Land Use Plan (OMNR 1982a)

Fisheries Management Objective

- To protect, enhance, maintain and rehabilitate fish communities and their environment in order to provide an optimum contribution of fish, fishing opportunities, and their associated benefits to society

Sport Fishing Objective

- To maintain opportunities for a diversified angling experience and meet the future angling demand for all species within the limits of sustained yield management

Commercial Fishing Objective

- To encourage the harvest of commercial fish populations when it is biologically feasible

Lake Trout Objective

- To manage for the survival and maintenance of significant lake trout populations as well as the provision of angling opportunities

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Northwestern Ontario Strategic Land Use Plan (OMNR 1982c)

Fisheries Management Objective

- To protect, rehabilitate, enhance and maintain Ontario's fish communities and their environment to provide an optimum contribution of fish, fishing opportunities and associated benefits to society

Sport Fishing Objective

- To meet the demand for sport fishing consistent with the limits of an optimum sustained yield

Commercial Fish Objective

- To encourage the harvest of commercial fish when it is biologically and economically feasible

Lake Trout Objective

- To provide for the maintenance, protection and enhancement of lake trout populations, and to provide recreational angling opportunities to the general public for this species, based on an optimum sustainable yield

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Strategic Planning for Ontario Fisheries (SPOF)(OMNR 1976; revised 1990)

Goal For Ontario Fisheries

- Healthy aquatic ecosystems that provide sustainable benefits to satisfy, in part, society's present and future requirements for a high quality environment, wholesome food, employment and income, recreational activity, and cultural heritage

Objectives

- To protect healthy aquatic ecosystems;
- To rehabilitate degraded aquatic ecosystems; and
- To improve cultural, social and economic benefits from Ontario's fisheries resource

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MNR Strategic Directions 1989 (Draft) (OMNR 1989)

Ministry Goal

- To ensure the sustainability of healthy ecosystems and manage them for the benefit of the people of Ontario